The 2-channel EPR spectrometer Radiopan SE/X- 254x for relative quantitative measurements

(2-kanałowy spektrometr EPR Radiopan SE/X-254x do względnych pomiarów ilościowych)

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In earlier works [1, 2] the general outline and possible application of 2-channel EPR spectrometer enabling the measurements of the number of spins in investigated material related to the standard sample has been described. The simplified diagram of such spectrometer is shown in *Fig. 1*.

The required condition to build such spectrometer is to ensure the possibility of simultaneous recording of the EPR signals coming from the investigated and from reference sample. In addition to the basic blocks of the EPR spectrometer like the magnetic field source (the electromagnet with magnetic field controller), microwave unit, basic modulation-receiving unit (typically of 100 kHz frequency), auxiliary units (monitor, magnetic field meter etc.), console containing individual units, to construct 2-channel spectrometer the following important blocks there are absolutely needed:

– double resonator enabling to put inside both tested and reference samples;
– additional modulation-receiving unit, enabling to receive the EPR signal from the reference sample. To avoid reciprocal interference, the frequencies of both units (additional and basic) should be much different;
– a system enabling the simultaneous recording of both EPR signals;

According to our knowledge, there is not commercial company offering 2-channel EPR spectrometer. It is not really the substantial problem (the list of potential recipients is rather limited), since depending on the requirements (and financial possibilities) such kind of spectrometer can be constructed through an advanced rebuilding of the existing, classical EPR spectrometer. In the last years at the Wroclaw University of Technology a few 2-channel X-Band EPR spectrometers have been completed with the use of our own construction units [3–5] and adoption of old units of the EPR spectrometers made by non-existing presently Radiopan company.

The 2-channel EPR spectrometer Radiopan SE/X- 254x

It has been found possible that on the basis of Radiopan EPR spectrometer SE/X- 254x series it is possible (at relatively small cost) to build a truly functional 2-channel EPR X-Band spectrometer. As the basic modulation-receiving path the existing analogue receiver with frequency of 100 kHz can be adapted, while as additional receiving path (for the signal from the reference sample) can be adapted, being practically not used, the second analogue receiver with frequency of 80 Hz. Evidently, it is essential to install a 2-chamber measuring cavity in place of the existing single cavity, and a special recording system of both EPR signals. Spectrometer of this type will be built for the Baltic State University in Kaliningrad (Russia). The reconstruction of this spectrometer has been done in two stages. In the first stage (already realized in 2007) spectrometer has been equipped with so-called digital magnetic field sweeper assuring magnetic field sweeping together with simultaneous recording of the EPR signal. For this purpose a special program *EPR System* has been designed with the function of controlling the whole process through a simple USB interface. In the second stage (2011–2012) spectrometer will be converted into the above presented 2-channel system. The view of the 2-channel Radiopan SE/X- 254x spectrometer console (with installed digital field sweeper) is shown *Fig. 2*.

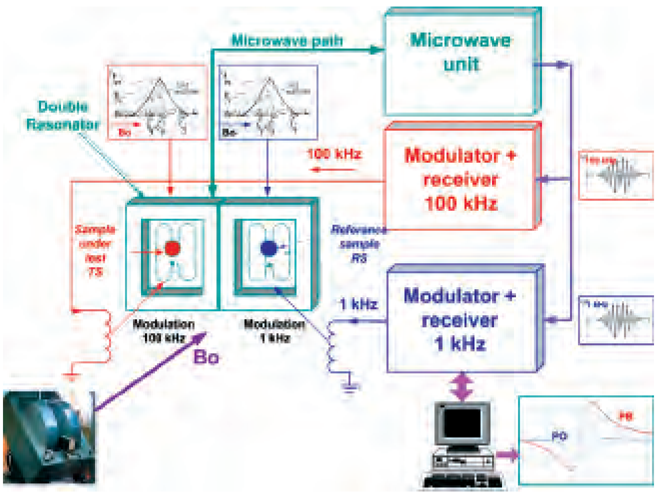


Fig. 1. Block diagram of the 2-channel EPR spectrometer
Rys. 1. Uproszczony schemat blokowy 2-kanałowego spektrometru EPR

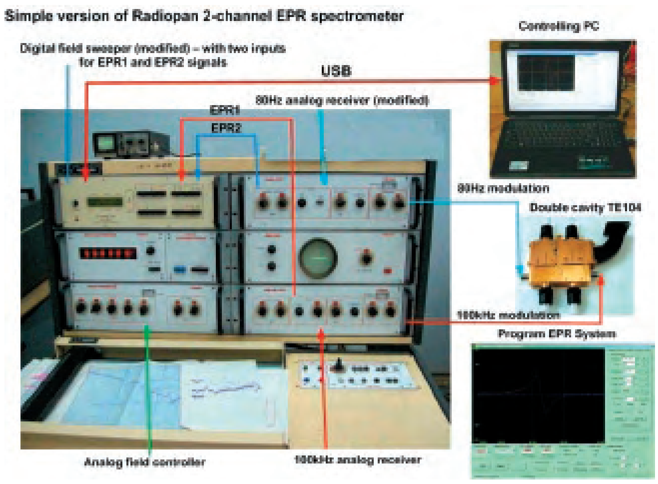


Fig. 2. Illustrative view of the 2-channel X-Band Radiopan SE/X- 254x EPR spectrometer with built-in digital field sweeper
Rys. 2. Schemat poglądowy spektrometru 2-kanałowego Radiopan SE/X-254x z wbudowanym cyfrowym układem przemiatania

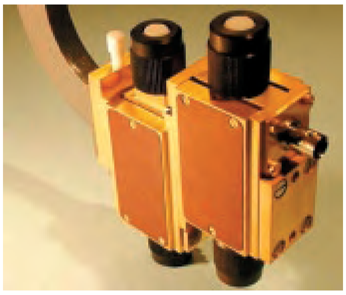


Fig. 3. The 2-chamber Radiopan rectangular cavity CX-104d (CAVIPAN Poznan)
Rys. 3. 2-komorowy rezonator prostokątny CX-104d – CAVIPAN (Poznań)

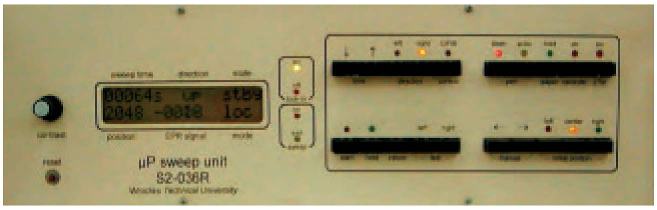
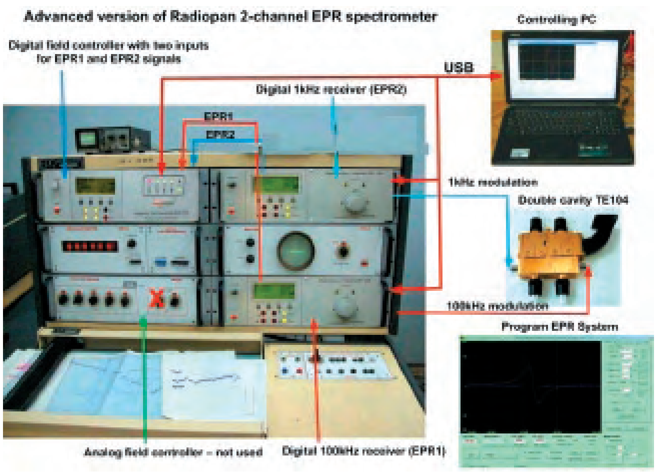


Fig. 5. Front view of the digital field sweeper
Rys. 5. Widok cyfrowego układu przemiatania od przodu



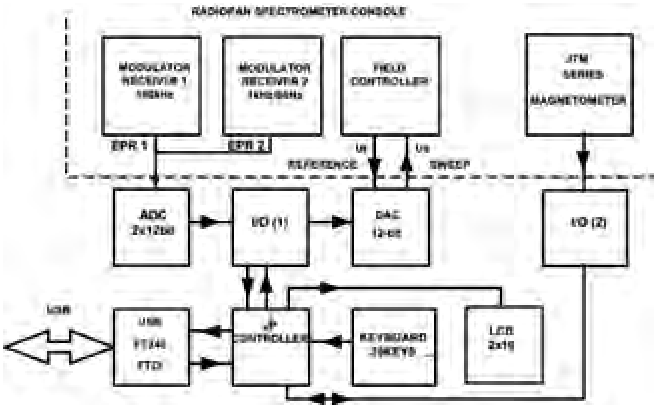


Fig. 6. Block diagram of the digital field sweeper
Rys. 6. Schemat blokowy cyfrowego układu przemiatania

Fig. 4. Illustrative view of 2-channel X-Band EPR Radiopan SE/X- 254x spectrometer with new digital units of Wroclaw University of Technology (digital magnetic field stabilizer and digital receivers of 100 kHz and 1 kHz)
Rys. 4. Schemat poglądowy spektrometru 2-kanałowego Radiopan SE/X-254x z cyfrowymi, nowymi blokami Politechniki Wrocławskiej – stabilizator pola magnetycznego oraz odbiorniki 100 kHz i 1 kHz

For the comparison in *Fig. 4* the similar spectrometer but with new units of Wroclaw University of Technology installed (the digital magnetic field stabilizer and digital receivers of 100 kHz and 1 kHz) is also shown. In this spectrometer the 2-chamber rectangular cavity CX-104d was adapted, constructed by binding of two identical standard CX-102d cavities. The view of such CX-104d cavity is shown in *Fig. 3* (this kind of cavities are offered by CAVIPAN company in Poznan, Poland).

Digital field sweeper and control program

The essential condition for computer recording of the EPR signal is to ensure the precise changing of the magnetic field (field sweep) with simultaneous converting of the analogue EPR signal into digital form followed by the storing it in computer memory. There are three possible solutions available:

a. Installation of a digital magnetic field controller, e.g. designed in the WUT as apart of a few research projects (the model still under the development).
b. Application of the digital field sweeper designed in the Wroclaw University of Technology. This unit has been designed mainly to be installed in old models of EPR spectrometers delivered from different companies, including those designed by Wroclaw University of Technology and Radiopan.
c. The use of special computer cards – ADC, DAC and I/O.

In the described spectrometer we decided to use of the digital field sweeper along with leaving analogue receivers of 100 kHz and 80 Hz – this solution is much cheaper than the version with the digital magnetic field stabilizer and with digital receivers 100 kHz and 1 kHz (*Fig. 5*). The advantage was taken from the fact that the analogue field stabilizer of the SE/X-254x spectrometer is equipped with the circuit enabling to change an magnetic field by digital method – this solution was earlier used for recording the EPR signals with digital XY Radiopan recorder. The solution based on the application of special computer cards wasn't taken into consideration – mainly due to its very small versatility: the spectrometer must be "associated" i.e. must be on-line with a given computer. The front view of the digital field sweeper is and its block diagram are shown in *Fig. 5* and 6 respectively.

The digital field sweeper is equipped with 2-input ADC converter enabling to convert both EPR analog signals coming from a sample under investigation and from the reference sample. The process of field sweeping and recording of both EPR signals is controlled with the special computer program EPR System, whose main window is shown *Fig. 7*. It is a modified, new version of the program, enabling the simultaneous recording of both signals. The program is equipped with so-called fast-sweep function (with time of 0.5 s), which is useful particularly for the selection of set parameters of the recording (gain of the path, bandwidth, phase shift, change of the so-called background etc.). Similarly as previous versions of the program EPR System, the present program enables the advanced processing of recording EPR signals as e.g. smoothing, integrating, differentiation, adding up, comparing with oneself, putting of spectra etc. Additionally, the program makes possible the transformation (recounting) of the spectra according to the implemented mathematical relation – it is particularly useful for finding characteristic parameters of recorded EPR signals.

Since magnetic field stabilizer as well as both receiving paths are analogue, their keyboard settings must be introduced into the program EPR System in order to get the appropriate scale of recorded EPR signals and in order to enable the later mathematical processing of recorded EPR signals. The following settings should be included: the central magnetic field, sweep range, gain of both receiving paths, modulation amplitude of both paths, phase shift, DC background levels, time constant of output filters etc. Additionally, the program enables to type in the current microwave frequency (read out from the scale of the microwave meter) and the value of the microwave power (read out from the scale of the microwave attenuator). These values are useful for comparing of individual results of measurements.

Since the installed digital field sweeper is controlled by a simple USB interface, the spectrometer can be controlled practically with any computer – stationary or portable.

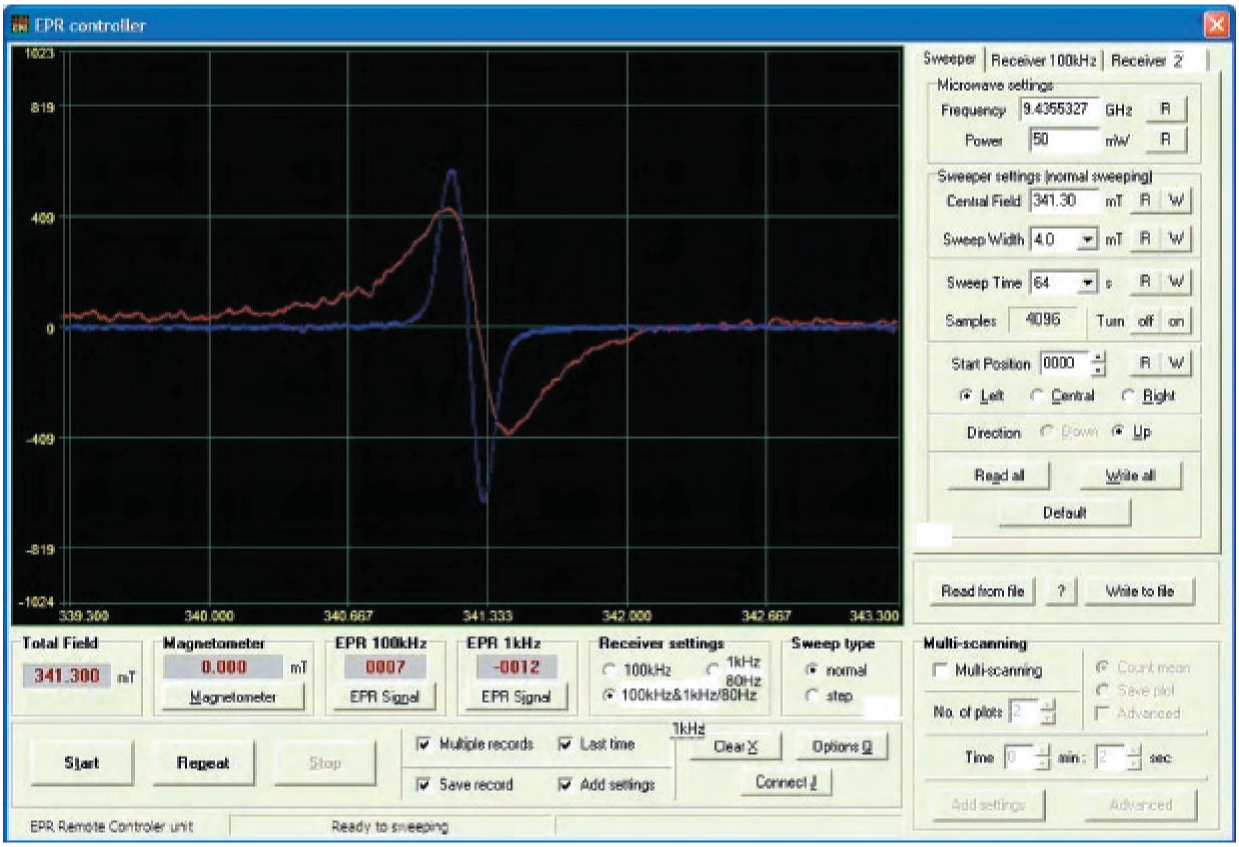


Fig. 7. Main window of the control program EPR System. Rys. 7. Okno główne programu sterującego EPR System

Summary

From the information presented above it is clearly seen that under a relatively small financial outlay it is possible to build a completely new research instrument, that is not offered by the world instrumentation industry. The possibility of the exact measuring of the EPR signal intensity is very useful in many fields of science and technology in which EPR spectrometry is in use.

The truly economic solution (according to the authors opinion) meeting this requirement is to complete a 2-channel EPR spectrometer following the way proposed in present work. However, is it the only way (not necessarily the cheapest one) enabling to achieve such result? Rather not, indeed! It is namely possible to complete the 2-channel EPR spectrometer by adapting of almost everyone units of any spectrometer. Due to the widespread application of X band in EPR spectrometry the easiest way to complete 2-channel EPR spectrometer together is to adapt for this purpose a spectrometer of this band. The application of different frequency band – smaller or higher as compared with X band – requires a suitable microwave unit and an appropriate double resonator. The options enabling to choose another frequency double resonators are given in our earlier work [1]. Unfortunately, the 2-channel EPR spectrometer operating in the other microwave band is becoming more expensive than that of X band.

Nevertheless, L-Band 2-channel spectrometer, for example, could be useful for the detection of irradiated food and accidental dosimetry [6–8], Suppressing of electromagnetic fields by water is in L band much smaller than in higher frequency bands (X, K, Q). For that reason the L-band spectrometer is useful for testing of wet substances or those containing a lot of structural water. Most of food and biological materials belongs to this group of substances. In contrast to L band, the samples with big contents of water are very difficult to measure or are not measurable at all if higher frequency bands (X, K, Q) are used.

It is rational to believe that such 2-channal L-band spectrometer could find application not only in sanitary-epidemiological stations, but also in research units and companies dealing with the examination, processing and distribution of biological materials as well as of all kinds of foods of domestic origin or imported from abroad.

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