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HARDWARE-SOFTWARE COMPLEX FOR A STUDY OF HIGH-POWER MICROWAVE PULSE PARAMETERS

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An instrumental complex is developed for a study of high-power microwave pulse parameters. The complex includes a bench for calibrating detectors and a measuring instrument for evaluating the microwave pulse parameters. The calibration of the measurement channels of microwave pulses propagating through different elements of the experimental setup is an important problem of experimental research. The available software for calibration of the measuring channels has a significant disadvantage related with the necessity of input of a number of additional parameters directly into the program. The software realized in the Qt 4.5 C++ medium is presented, which significantly simplifies the process of calibration data input in the dialog mode of setting the parameters of the medium of microwave pulse propagation.

Keywords: calibration, measuring channels, microwave pulse, software, Qt 4.5 C++ medium, microwave pulse parameters.

INTRODUCTION

High-power microwave generators with output power of about $7\cdot10^4$ W are used for sensing dense layers of the atmosphere. An adequate measurement of the pulse characteristics both directly on the generator output and after interaction with the propagation medium is of great significance. The calibration of the frequency-independent and frequency-dependent detectors used for a study of the microwave pulse parameters is described in [1]. The frequency-dependent detector includes a beyond-cutoff attenuator and is used to estimate the microwave pulse spectrum. The detectors were calibrated using a computer code developed in the *MathCad* medium. This software is very inconvenient for an experimenter, because it requires input of additional parameters directly into the code when the properties of the microwave pulse propagation medium are changed.

The software intended for detector calibration created in the Qt 4.5 C++ medium [2] is presented in this paper. Unlike the *MathCad* software, all necessary additional components are input from the table comprising the file of input parameters [3].

CALIBRATION OF MICROWAVE PULSE DETECTORS

The block diagram of the bench for calibration of the receiving detectors is shown in Fig. 1. Pulses from the calibration microwave generator operating in the pulse mode are input to two microwave detectors, frequency-independent and frequency-dependent ones, containing a beyond-cutoff attenuator and a coupler through the coaxial-wave transition, T-joint, attenuators, and other elements of the experimental setup. The mean power is measured at the coupler using a standard power meter. Calibration curves of detectors are constructed taking into account the deviation of the pulse shape of the calibration microwave generator from rectangular.

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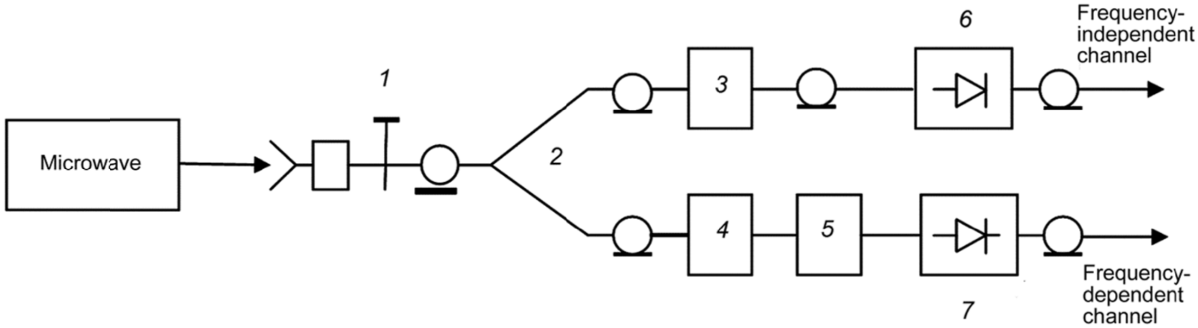

Fig. 1. Block diagram of the calibration bench with detectors one of which is frequency-dependent. Here *1* denotes the coaxial-wave transition, *2* denotes the T-joint, *3* and *4* denote the fixed attenuator, *5* denotes the beyond-cutoff attenuator, and *6* and *7* denote the detector heads.

During calibration of the detectors, 8 levels of pulse power were formed from 15 to 33 dB·W using the attenuator of the microwave generator. These powers with steps of 3 dB were approximately equal to 15.625, 31.25, 62.5, 125, 250, 500, 1000, and 2000 W at frequencies from 2700 to 3700 MHz with a step of 100 MHz (11 frequencies). Output voltages of the frequency-independent and frequency-dependent detectors at these frequencies of microwave pulses were registered with a four-channel oscilloscope and stored in two files comprising 1001 readings each with a time interval of 2 ns. Thus, 88 files used for obtaining the calibration curves were recorded from each sensor during calibration. The use of 1001 readings significantly increases the accuracy of estimation of the calibration coefficients.

MATHEMATICAL DESCRIPTION OF THE CALIBRATION PROCESS

As demonstrated investigations [1], the calibration curves of the linear (frequency-independent) and nonlinear (frequency-dependent) detectors are described fairly well with a polynomial of the sixth order; moreover, the coefficients of the 1st, 2nd, 5th and 6th degrees of the polynomial are significant, whereas the 3rd and 4th degrees of the approximating polynomial contribute no more than 1–2%. Thus, the calibration polynomial at a fixed frequency for a preset pulse power of the microwave generator can be represented in the form

$$F(x) = a_1 \cdot x + a_2 \cdot x^2 + a_5 \cdot x^5 + a_6 \cdot x^6 , \tag{1}$$

where $a_1, a_2, a_5,$ and a_6 are unknown coefficients, x is the value of the detector signal at the calibration frequency.

The least squares method was used to calculate the coefficients of the calibration polynomial from the experimental data obtained. According to this method, the least-squares functional of the form

$$F_1 = \sum_{j=1}^{8} \sum_{i=1}^{1001} \left(U_{\text{ild}} - \left(a_1 x_i + a_2 x_i^2 + a_5 x_i^5 + a_6 x_i^6 \right) \right)^2 \to \min \tag{2}$$

is formed for the frequency-independent detector at each frequency of the microwave generator, where U_{ild} are discrete values of voltages of the microwave generator at a fixed frequency for the *j*th level of pulses from the microwave generator, $j = 1,\dots,8$, $a_1, a_2, a_5,$ and a_6 are the calibration coefficients of the detector at the fixed frequency, *i* is the serial number of the detector reading at the preset frequency for the fixed level of signal of the microwave generator, and x_i is the value of the *i*th detector reading at the calibration frequency. Analogously, the least-squares functional F_2 is written for the frequency-dependent detector.

The functional reaches a minimum when the partial derivatives of the functional with respect to the unknown coefficients are equal to zero:

$$\frac{\partial F_1}{\partial a_{1i}} = 0, \quad \frac{\partial F_1}{\partial a_{2i}} = 0, \quad \frac{\partial F_1}{\partial a_{5i}} = 0, \quad \frac{\partial F_1}{\partial a_{6i}} = 0\,. \tag{3}$$

From here we obtain the system of linear equations for determining the four calibration coefficients for the linear detector at each of the 11 frequencies:

$$\begin{aligned}
\sum_{j=1}^{8}\sum_{i=1}^{1001} U_{\text{ild}} x_i &= \sum_{j=1}^{8}\sum_{i=1}^{1001}\left(a_1 x_i + a_2 x_i^2 + a_5 x_i^5 + a_6 x_i^6\right) x_i\,,\\
\sum_{j=1}^{8}\sum_{i=1}^{1001} U_{\text{ild}} x_i^2 &= \sum_{j=1}^{8}\sum_{i=1}^{1001}\left(a_1 x_i + a_2 x_i^2 + a_5 x_i^5 + a_6 x_i^6\right) x_i^2\,,\\
\sum_{j=1}^{8}\sum_{i=1}^{1001} U_{\text{ild}} x_i^5 &= \sum_{j=1}^{8}\sum_{i=1}^{1001}\left(a_1 x_i + a_2 x_i^2 + a_5 x_i^5 + a_6 x_i^6\right) x_i^5\,,\\
\sum_{j=1}^{8}\sum_{i=1}^{1001} U_{\text{ild}} x_i^6 &= \sum_{j=1}^{8}\sum_{i=1}^{1001}\left(a_1 x_i + a_2 x_i^2 + a_5 x_i^5 + a_6 x_i^6\right) x_i^6\,.
\end{aligned} \tag{4}$$

A solution of system of equations (4) makes it possible to derive a 4×11 matrix of calibration coefficients, i.e., 4 coefficients for each of the 11 calibration frequencies.

DESCRIPTION OF THE SOFTWARE

The calibration software was implemented in the Qt 4.5 C++ medium. The project of the of software consisted of 5 modules successively providing the function of loading of calibration files recorded with digital oscilloscopes, calculation of 4 calibration coefficients for the detectors at each of the 11 frequencies, construction of the calibration curves, and recording of the calibration coefficients in two files. The obtained calibration coefficients are then used to calculate the microwave pulse parameters. The calculated calibration coefficients are shown as plots for the frequency-independent and frequency-dependent detectors (Figs. 2 and 3).

MEASUREMENTS OF THE MICROWAVE PULSE PARAMETERS

An increasing efficiency of data processing allowed the capabilities of the experimental setup to be expanded, namely, a mobile detector was added whose motion on the surface of the imaginary sphere with the center placed at the emitting window of the generator allowed the spatial distribution of the radiation intensity to be analyzed, i.e., the directional pattern of radiation emitted by the microwave generator to be measured. The block diagram of the experimental setup for evaluation of the parameters of microwave pulses propagating through the measuring channel and of other setup parameters is shown in Fig. 4. Signals from the experimental setup were detected by two four-channel digital oscilloscopes and recorded in the corresponding files. In this case, the coefficients calculated depending on the measured parameters were used for processing of the data obtained. In addition to signals from the detectors, the

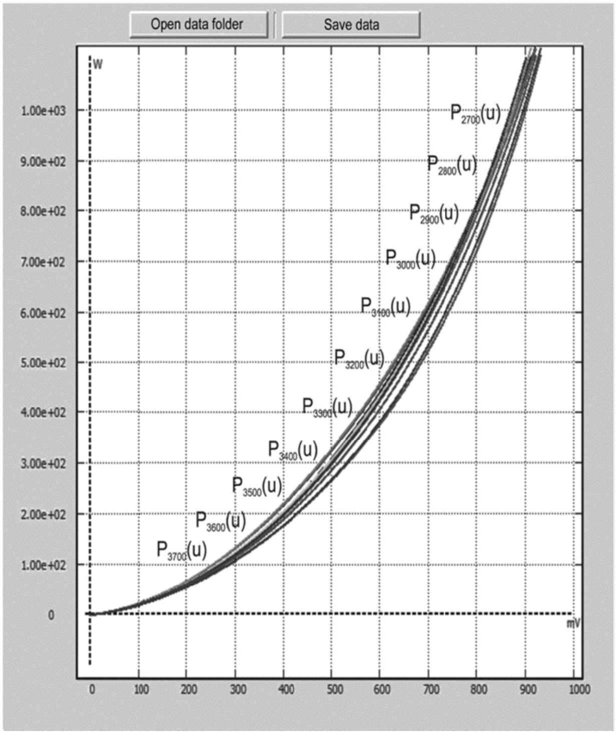

Fig. 2

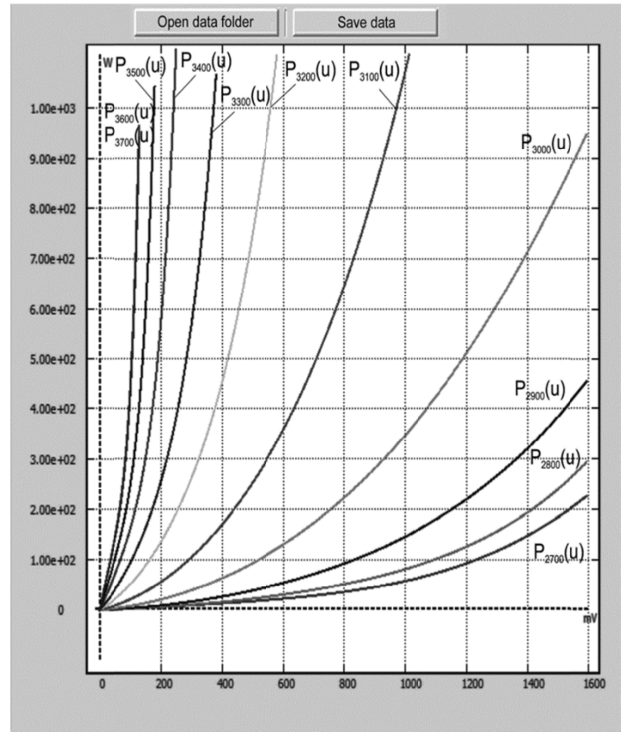

Fig. 3

Fig. 2. Calibration curves for the frequency-independent detector.

Fig. 3. Calibration curves for the detector with the frequency-dependent beyond-cutoff attenuator.

pulsed current and the voltage of the microwave generator were also recorded. The Rogowski loops were used to record the triode current.

The attenuation coefficients of the attenuators and other parameters characterizing the experimental setup state were presented in the initial data table that could be run through before processing to make necessary corrections if required. The corrections were written in the file and stored until the end of calculations.

STRUCTURE OF THE SOFTWARE

During the experiment, the results from two four-channel oscilloscopes were recorded in two folders. The name of each file contained the serial number of the experiment that allowed the corresponding files to be chosen for the subsequent processing. The input parameters necessary for processing of the experimental results were stored in the data file read at the start of the program. These values were placed in the table. When processing the experimental results, the experimenter can adjust the input parameter values if the experimental conditions changed. After reading of the experimental data, the virtual plots were drawn on which signals from the sensors were superimposed. When studying the spatial distribution of microwave radiation, the additional file with the coordinates of the mobile detector was added.

After conversion of signals from sensors with allowance for the calibration coefficients, the plots were visualized. Different sections of the plots could be examined in detail. To this end, temporal cutoff of the data was used with preset initial and final cutoff points. The parameters were quantitatively estimated using mobile markers. To

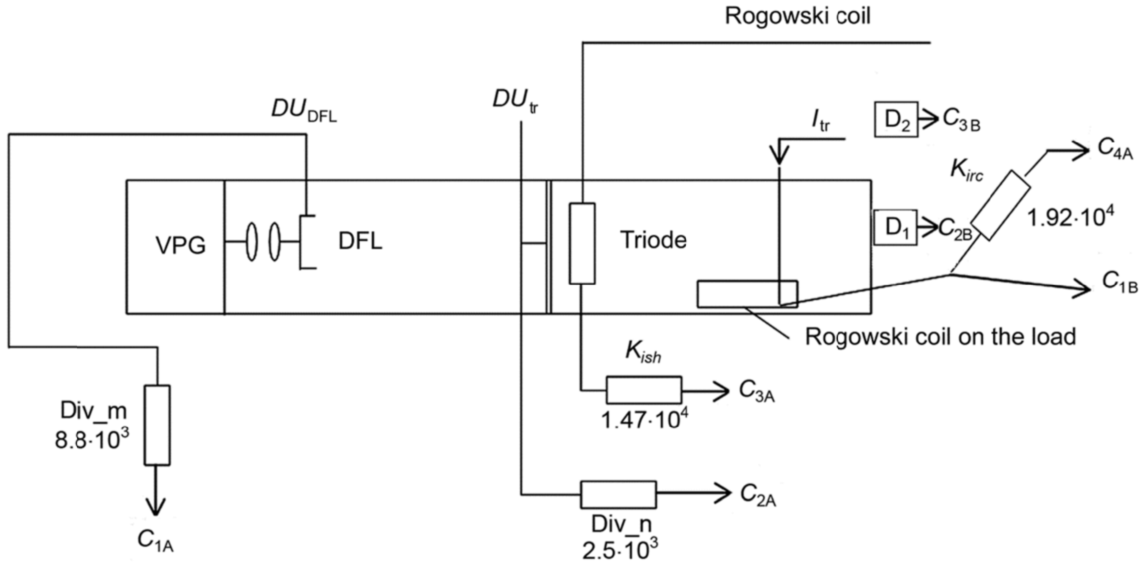

Fig. 4. Diagram of the experimental setup with measuring channels comprising the voltage pulse generator VPG, the double forming line DFL, the immobile detector D_1, the mobile detector D_2, the voltage from the double forming line DU_{DFL}, the VPG voltage $C_{1\mathrm{A}}$ (U_m) (supplied to the 1st channel of the oscilloscope A), the triode divider voltage DU_{tr}, the triode voltage $C_{2\mathrm{A}}$ supplied to the 2nd channel of the oscilloscope A (U_n), the triode current $C_{3\mathrm{A}}$ supplied to the 3rd channel of the oscilloscope A, the current $C_{4\mathrm{A}}$ on the Rogowski loop supplied to the 4th channel of the oscilloscope A, the triode current $C_{1\mathrm{B}}$ supplied to the 1st channel of the oscilloscope A, the triode current I_{tr}, the VPG attenuator Div_m, the diode voltage divider Div_n, the attenuator K_{ish} in the triode current chain, the coefficient K_{irc} in the current measuring chain in the Rogowski loop under triode load, the voltage from the immobile detector $C_{2\mathrm{B}}$ (U7) supplied to the 2nd channel of the oscilloscope B, and the mobile detector voltage $C_{3\mathrm{B}}$(U1d) supplied to the 3rd channel of the oscilloscope B.

estimate current values of the microwave pulse amplitude and other parameters of the experimental setup from an individual plot, the first mobile marker representing a section of the straight line displaced along the plot was used; the quantitative value of the parameter was displayed in the corresponding window.

The time delay between individual parameters was registered using the second mobile marker representing a section of the straight line. Displaying it in the corresponding window, the time delay between the positions of the first and the second markers could be determined. The plots of the parameters of the experimental setup and the microwave pulse waveforms recorded by the immobile and mobile detectors are shown in Fig. 5.

The practical procedure of measuring channel calibration and evaluation of the microwave pulse parameters demonstrated that the experimenter using the developed software faced no difficulties in both calibration and evaluation of the microwave pulse parameters and other parameters of the experimental setup.

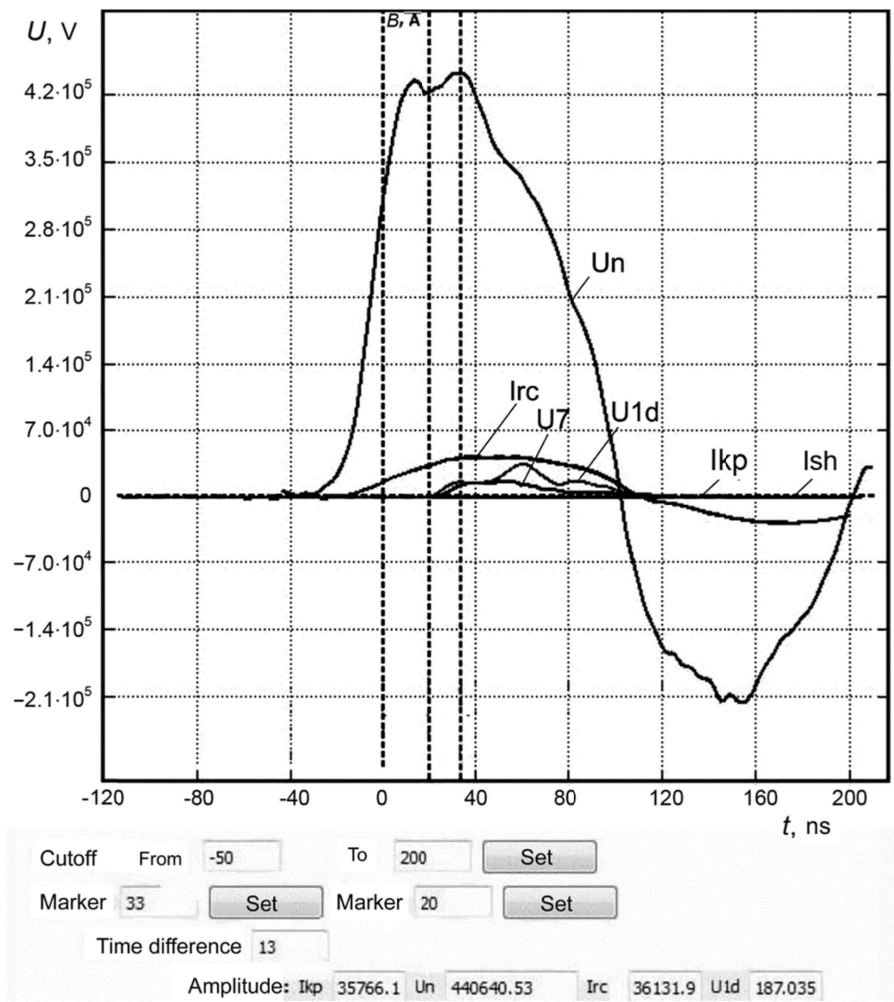

Fig. 5. Plots of the microwave pulse and other parameters of the experimental setup: the current in the Rogowski loop Ikp(C_{1B}), the triode current Ish(C_{3A}), the triode voltage Un(C_{2A}), the immobile detector voltage U7(C_{2B}), the current in the Rogowski loop on the load Irc(C_{4A}), and the mobile detector voltage U1d(C_{4B}).

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