Although realization of the ohm by direct referring it to the constants of nature is possible, there is no known quantum phenomena allowing for direct realization of the farad and the henry. The only option is comparison of the capacitance or inductance with resistance derived from the quantum Hall effect. Therefore, high-precision comparison circuits and systems have to be developed to enable the most accurate reproduction of the unit of measure for capacitance and inductance. Principle of operation of these circuits is based on a direct comparison of the device under test (DUT) with the reference standard (REF) of sufficiently high accuracy and stability. Especially differential and ratio comparison circuits are used for this purpose. Currently, ratio measurements dominate, especially in impedance measurements, mainly due to the dynamic development of the quantum and digital multichannel AC voltage sources. In such measurements the parameters of the DUT are calculated by the measured ratio of the unknown impedance to the reference impedance standard of well known parameters. It is commonly known that the most accurate impedance comparison requires four-terminal pair (4TP) coaxial circuit. The unsolved problem in the 4TP comparison circuits is reduction of the uncertainty of impedance measurements to the level 10^{-6} without using very expensive multi-channel AC voltage standard based on Josepshon effect. Another scientific problem is the development of effective methods of testing such an accurate measurement system that would allow ~~designers~~ for uncertainty evaluation of the system and detection of error sources in the measurement system at the stage of prototyping. Both of the above mentioned problems will be solved within the project. Therefore, the research objective of the project is to develop a digital non-quantum system for impedance comparison that will be more accurate than presently available circuits.
Reason for choosing the research topic is that:

1) Electrical impedance measurements are ubiquitous in the manufacturing and characterization of electrical and electronic devices, and in the design, manufacturing and testing of electronic circuits. For example, several types of sensors: resistance thermometers, capacitive displacement sensors, proximity sensors (including touch screens), barometers and hygrometers convert the non-electrical quantity of interest into an electrical impedance output. Electrical impedance spectroscopy also plays a very strong role in non-destructive tests for a wide array of analyses, such as chemical and biological characterization of solids, liquids and biological materials. Also measurements of electrical properties of materials like permittivity, permeability or dielectric loss is based on accurate impedance measurements of a fixture or cell. Metrological traceability of the impedance measurements is a prerequisite for the reliability and comparability of results of such analyses, because traceable impedance measurements require calibrated instruments. Therefore, a high-precision systems for calibration of *RLC* standards are necessary to ensure traceability of impedance measurements.

2) There is lack of sufficiently accurate impedance measurements systems that are accessible for small National Metrology Institutes and other metrology laboratories. The only available system for impedance comparisons at 10^{-6} uncertainty level is a complex, extremely expensive quantum AC voltage system operated by a highly skilled technician.

A conclusion drawn from the recent studies is that reducing uncertainty of the non-quantum impedance comparison system to the level 10^{-6} requires development of a system with specialized high-performance two-channel source of AC voltage and associated instruments, like multiplexer, injection transformer and sampler. Such a system have to adopt many techniques for interference-free measurements. These techniques, like current equalization, very good magnetic and electric screening, designing a precise low-noise electronic circuits, phase-sensitive detection, elimination of thermoelectric forces, isolating a noisy instruments, eliminating inductive coupling, sampling methods and many others aren't commonly used in commercial precision LCR meters.

Our concept of the system for comparison of 4TP impedances is based on a bridge circuit composed of the special two-channel AC voltage source and two impedances Z_1 and Z_2 being compared. Balancing the bridge requires the use of additional three sources of sinusoidal AC voltage and two null detectors. When the bridge is balanced, the 4TP definition of the impedance standards is realized and the complex impedance ratio corresponds to the complex voltage ratio at the high terminals of Z_1 and Z_2 ($Z_1/Z_2 = -U_1/U_2$). The measurements of the voltage ratio is performed through sampling the voltages U_1 and U_2 using the single digitizer of PXI system and the coaxial multiplexer .The proposed technique implies that the two voltages are not measured simultaneously but successively. The main advantage of successive sampling is that the gain- and other errors of the digitizer cancels out in the ratio calculation as long as it is stable during the time needed to measure the two voltages. Two another digitizers of PXI system will be used to obtain Kelvin balance of the bridge that eliminates influence of connection impedances.

As mentioned above, the key issue for improving accuracy of non-quantum impedance comparison is to develop a novel high-precision two-channel source of digitally synthesized AC voltage. The source developed within the project will be characterized with extremely stable amplitude and phase and nanovolts/microradian resolution of magnitude and phase setting, respectively. Moreover, it will be fully synchronized with the sampler and the multiplexer. Several investigation will be performed and new techniques will be applied to meet the demanded extreme high accuracy. Metrological properties of the source, especially stability of the voltage ratio and output impedances will be examined. Moreover, non-linearity error of the digitizer will be investigated. It is suspected that this error will be one of the major components of the system uncertainty.

Another task to meet the assumed accuracy requirement is to design, construction and investigation of the high-precision coaxial multiplexer, injection transformer and automated permuting capacitor device. The multiplexer and injection transformer are two autonomous components of the digital system, and a permuting capacitor device will be used for non-linearity testing of the main digitizer. Many problems, like proper electrostatic shielding, minimization and equalization the shunt impedances have to be solved within this task.

All previously designed and tested elements will be connected into one system. A program that controls comparison process and calculates the impedances ratio will be developed. Due to the need to balance two dependent voltages in the system it will be necessary to develop a specific balancing algorithm that once implemented in the control program will enable full automation of the comparison process.

The system will be validated using the traditional method utilizing calibrated standards and the triangle comparison method that is innovative in the field of ratio impedance comparison and in which development the authors contributed a lot. Using two independent methods of validation will increase reliability of the system. All calibration results will be analyzed and uncertainty budget will be prepared. Based on the budget a conclusion about final accuracy of the system will be drawn.