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ANALYSIS AND STUDY OF PROPERTIES OF DIGITAL UNBALANCED IMPEDANCE COMPARATORS

ABSTRACT

Basic circuits dedicated for accurate impedance measurements are used primarily for comparisons of impedance standards. More and more often, the need for their use is associated with measuring the parameters of electronic components and impedance sensors. Another example of the use of this type of circuits concerns impedance spectroscopy used in various types of physical and chemical research.

Measurements of R, C, L standards are usually performed using balanced circuits (balanced comparators, balanced bridges). Compared to unbalanced measurement circuits, balanced measurement circuits provide lower comparison uncertainty. In recent years, one of the constantly improved solutions of impedance bridges are circuits with digital sinusoidal voltage sources (fully digital impedance bridges), in which the equilibrium state is achieved by precise regulation of the amplitude and phase of sinusoidal voltages generated using digital methods - methods using direct digital synthesis. The ratio of the compared impedances is determined by using the values of the amplitudes and phases of the output voltages of digital sources in equilibrium (digital bridges with calibrated voltage sources) or by measuring the ratio of voltage drops on the compared standards using an additional sampling circuit (sampling digital bridges, digital bridges with measurement of the complex voltage ratio). The use of digital sinusoidal voltage sources (DSVS) facilitates the automation of the bridge balancing process. This eliminates the experimenter from the time-consuming process of comparing impedance standards. However, balanced digital bridges require high resolution adjustment of the amplitude and phase of the DSVS used in the balancing process. The balancing process also requires repeated, phase-sensitive measurements of very small unbalance voltages, which leads to an extension of the balancing process steps and, consequently, to an extension of the measurement time.

Elimination of the above disadvantages is possible in unbalanced circuits (unbalanced comparators, unbalanced bridges). In unbalanced digital comparators, which are most often systems with measurement of the complex voltage ratio, the ratio of compared impedances is determined by measuring the ratio of voltage drops across the compared impedances and by measuring the unbalanced voltage in a state close to the equilibrium of the bridge.

There is then no need to use sources with precise regulation of the amplitude and phase of the output voltages. This significantly simplifies the construction of the bridge and shortens the time required to perform comparison of the standards.

In the work, the author puts forward the thesis that by using digital unbalanced impedance comparators with measurement of the complex voltage ratio, under certain conditions it is possible to measure the impedance ratio with an accuracy at the level that is achievable in digital balanced systems. Thesis is proven by:

- analysis and comparison of the metrological properties of selected unbalanced impedance comparators with the measurement of the complex voltage ratio,
- analysis and simulation tests of the accuracy of measurement of the complex voltage ratio carried out using a selected digital signal processing algorithm,
- development and testing of the physical model of an unbalanced digital impedance comparator with measurement of the complex voltage ratio and preparation of the uncertainty budget for the measurement of the R-R, C-C and R-C type impedance ratio,
- analysis of experimental test results obtained using an unbalanced digital comparator with those obtained using a balanced comparator in terms of measurement accuracy.

In the thesis characteristics of digital unbalanced impedance comparators are presented. Their division is presented according to the method of measuring voltages and according to the method of determining the impedance ratio. Two measurement methods are described, differing in the way they perform impedance ratio calculations. When using the first one, the impedance ratio is measured in a classic way, i.e. by calculating in subsequent balancing steps the values of the amplitude and phase settings of the voltages generated by digital sources, while when using the second one, the interpolation method proposed by the author is used. In the thesis the electrical diagram and mathematical model of a digital unbalanced comparator are presented. Models of compared standard impedances are presented which are used to determine the measurement uncertainty formulas of the ratio of dominant components and the difference or sum of residual components of various types of compared impedances. An analysis of the uncertainty of measurement of the components of the complex voltage ratio is presented, where many error sources i.e. quantization errors and linearity of the measurement system are analyzed and assuming that the Discrete Fourier Transform (DFT) is used to determine the two signals amplitude and angle of the phase shift. The results of simulation studies of the impact of the uncertainty of measurement of the relative unbalance voltage components and parasitic capacitances for different voltage frequencies reproduced by DSVS on the accuracy of measurement of the impedance ratio components are presented. One of the chapters of the work concerns experimental research on developed chosen circuits of digital unbalanced impedance comparators. Schematics of two developed physical comparator circuits are presented. The way in which individual elements of the measurement setup should be configured is described in detail. The chapter contains the results of measurements of the R-R, C-C and R-C type impedance ratios for various combinations of the values of the compared standards and for various measurement frequencies. Uncertainty budgets for measuring the components of the impedance ratio are evaluated. The measurement results of the ratio of dominant components and differences in residual components are presented in the form of charts, which include the results obtained using the presented unbalanced comparators and the balanced comparator. Tests are also carried out for standards calibrated at the Central Office of Measures (polish Główny Urząd Miar - GUM). Based on the measurement results, the conditions under which an unbalanced digital comparator should operate are presented so that the accuracy of the impedance ratio measurement is at the level that is achievable in a balanced digital comparator. The last chapter, which is devoted to summarizing the research results presented in the thesis, also includes the directions for further research to be conducted by author on digital unbalanced impedance comparators.