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Evaluation of Air Dielectric Four-Terminal-Pair capacitance standards using Resonance Frequency of Impedance Elements

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Abstract

A new method is proposed for the evaluation of air dielectric four-terminal-pair capacitance standards of nominal values 100 pF and 1000 pF using resonance frequency of impedance elements. It involves the determination of residual inductive and capacitive parameters of simple electrical-circuit-model of capacitance standards and thereafter computation of effective capacitance as a function of frequency up-to 10 MHz. The reference capacitance and residual capacitive parameters are measured using capacitance bridge and residual inductive parameters are estimated using measured resonance frequencies. The reported work will be helpful in the establishment of calibration services for capacitances up-to 10 MHz at CSIR-National Physical Laboratory. The uncertainty in measurement of effective capacitance is evaluated at $k = 2$ as per guide to the expression of uncertainty in measurement. The uncertainty budgets for 100 pF and 1000 pF capacitance standards at 1 MHz and 10 MHz respectively are also provided to analyze the sources of uncertainty contributing to the final uncertainty in measurement.

Keywords: four-terminal-pair, capacitance standards, resonance frequency, impedance, uncertainty

1. Introduction

CSIR-NPL is the premier research and development institute in the field of physical science and is also the National Measurement Institute of India which provides dissemination of traceability through calibration services. It is the custodian of national standards of measurement of various electrical and electronic parameters in India at apex level. The present work is performed at LF, HF impedance and DC Metrology section of CSIR-NPL, which is mainly responsible for the establishment, maintenance and advancement of measurement capabilities of impedance at low and high frequency (HF) (> 10 kHz), voltage, current, charge and resistance at dc level. The work performed is the part of the establishing the measurement traceability for capacitance above 10 kHz. The set of ultra precision coaxial air-lines is maintained as a national standard of impedance at HF and its realization is principally achieved with reference to the SI base units of the meter and the second [1]. The air dielectric four-terminal-pair (4TP) capacitance standards of Agilent 16380A type and three terminal (3T) GR1404 type capacitors are used as reference or secondary standards of impedance at HF. In recent past 3T [2] and 4TP capacitance standards [3] have been evaluated at high frequency at CSIR-NPL in the context of establishing the measurement traceability for capacitance at HF.

Cutkosky defined 4TP capacitance standard as the most precise admittance and impedance standard [4]. The attempt for its characterization was initiated by Jones [5] by extrapolating low frequency capacitance values to values at high frequency. Suzuki proposed impedance matrix method for the evaluation of 4TP capacitors [6]. The frequency characteristics of 4TP capacitance standards are evaluated up to several MHz by Yonekura using advanced electrical equivalent circuit model of the standards [7]. The characterization of capacitors was also performed up-to 30 MHz using four-port scattering matrix [8], [9] method. The present paper proposed the new method for the evaluation of 4TP capacitance standards (Agilent's 16380A Type) of nominal values 100 pF and 1000 pF from 1 MHz to 10 MHz. The method is based on the measurement of resonance frequency of set of impedance elements, which is further used to compute effective value of each of 4TP capacitance standard as a function of frequency up-to 10 MHz.