JCSS Calibration System for Capacitance in Japan Electric Meters Inspection Corporation

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Abstract

This paper presents the calibration system of the Japan Calibration Service System (JCSS) for the capacitance standard. The capacitance standard in Japan Electric Meters Inspection Corporation (JEMIC) is maintained using a 100 pF capacitor and is supplied by the National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology (NMIJ/AIST). Furthermore, the capacitance standard is extended from 10 pF to 10 μF using a high-precision transformer bridge (10:1 ratio) based on the 100 pF capacitor. The best measurement capability (BMC) is 0.73 μF/F (k = 2) at 100 pF and 1 kHz.

1. Introduction

JEMIC, an organization, was established in 1965 on the basis of the Japan Electric Meters Inspection Corporation Law, fulfils the role of a public intermediate calibration organization on behalf of the government as regards the calibration of electrical standards for direct current and low frequency. Furthermore, JEMIC has nine laboratories all over the country, which are performing the calibration services for respective territories by receiving the supply of standards from the head office of JEMIC.

Nowadays, we have been performing the calibration of about 50,000 measuring instruments a year in the fields of electrical quantities, temperature, and photometry. In addition, JEMIC has maintained two types of calibration services: JCSS calibration, which is the domestic traceability system established under the Measurement Law, and JEMIC calibration based on JEMIC's original standard traced from the national standard. On the other hand, in order to satisfy the demand for calibration of a wide range from the industry, the national primary standard for capacitance maintained by NMIJ is extended in JCSS-accredited calibration laboratories.

In this paper, the details of the extending method and calibration service for capacitance are described. The capacitance of a 100 pF capacitor is calibrated at a frequency of 1 kHz with an expanded uncertainty of 0.73 μF/F ($k = 2$).

2. Traceability system

Table 1 shows the calibration range of the capacitance in JEMIC. The calibration of about 400 capacitors a year is performed on the coloring range (at capacitances ranging from 1 pF to 1 F and at frequencies ranging from 50 Hz to 1 MHz) in Table 1. The calibration range under JCSS is from 1 pF to 10 μF at 1 kHz, shown in the slanted line in Table 1.

The traceability system under JCSS is shown in Fig. 1. The secondary standard for capacitance is a 100 pF fused-silica

Table 1 Calibration range

Nominal Value	Frequency(Hz)							
	50	60	120	400	1k	10k	100k	1M
1 F								
0.1 F								
0.01 F								
0.001 F								
100 μF								
10 μF								
1 μF								
0.1 μF								
0.01 μF								
1000 pF								
100 pF								
10 pF								
1 pF								

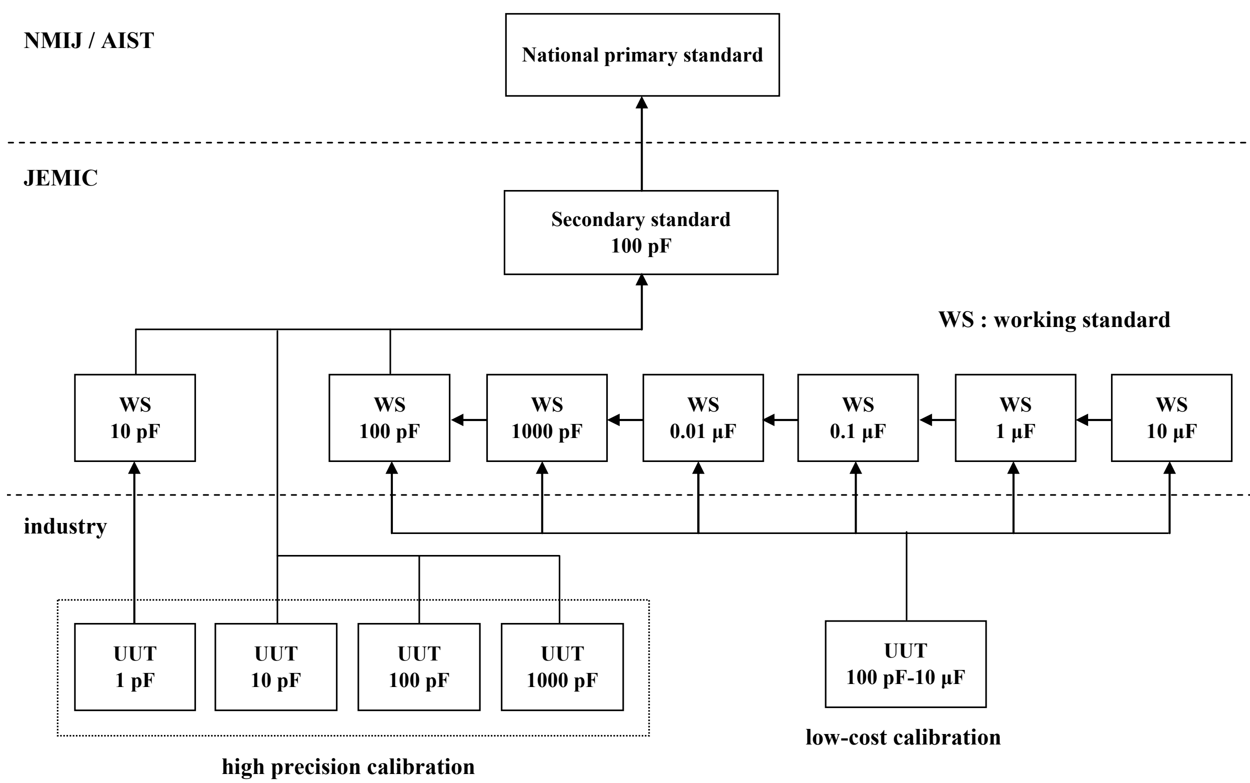

Fig. 1 Traceability system

capacitor (ANDEEN-HAGERLING 11A) which is calibrated by NMIJ at 1.592 kHz (angular frequency of $\omega = 10^4$ rad/s). Furthermore, the working standard (WS) capacitor from 10 pF to 10 μF is extended using a high-precision transformer bridge based on a 100 pF capacitor. The WS capacitor is a coaxial-type fused-silica capacitor with two-terminal structure or a ceramic capacitor with four-terminal structures.

BMC is 0.73 μF/F (k = 2) at 100 pF and 1 kHz. On the other hand, in order to satisfy the demand for low-cost calibration from the industry, an auto calibration system that combines an LCR meter with a coaxial scanner was constructed. Its BMC is 70 μF/F (k = 2) at 1 kHz. Table 2 summarizes the BMC in each rating. The laboratory environment is controlled at a temperature of 23 ˚C ± 1 ˚C and a humidity of 55 % ± 5 %.

Table 2 Best measurement capability

Nominal value	Expanded uncertainty (k=2)
10 μF	80 μF/F
1 μF	75 μF/F
0.1 μF	70 μF/F
0.01 μF	70 μF/F
1000 pF	0.79 μF/F
100 pF	0.73 μF/F
10 pF	0.79 μF/F
1 pF	1.1 μF/F

3. Extension of capacitance ranging

The capacitance standard of 10, 100, and 1000 pF is extended using a high-precision transformer bridge [1] developed in JEMIC on the basis of 100 pF. The bridge is a transformer bridge with a 10: 1 fixed ratio. A circuit diagram is shown in Fig. 2. T_2, with the principle of a two-stage transformer, acts as a standard for a 10: 1 ratio. Furthermore, because T_1 serves as an earthing device along with Z_1 and Z_2, T_2 is not affected by earth impedance. In other words, except for the parallel admittance between windings, T_2 is not affected. Because a correct ratio of T2 is transferred to T_1 by adjusting Z_1 and Z_2, a high-precision transformer bridge can be obtained.

The capacitance standard of 0.01, 0.1, 1, and 10 μF is extended using a high-precision four terminal-pair capacitance bridge (produced by SunJEM Co., Ltd) [2] designed in NMIJ on the basis of 1000 pF. Its bridge is a coaxial-type transformer bridge with a 10: 1 fixed ratio using the principle of the Kelvin double bridge. A circuit diagram is shown in Fig. 3. Because the transformer used as the standard of the voltage ratio of this bridge has the structure of a two-stage transformer, the influence of the voltage drop of the cable connected with the transformer can be neglected. This bridge is equipped with an adjustable current source so that the current does not flow through the principal winding. Under this condition, a definition point of the impedance in the four terminal-pair method is fixed using this electric current source, and a 10:1 impedance ratio is measured. The combining network is used to exclude the influence of impedance sources such as cables used for connecting C_1 and C_{10} in series, and high-precision calibration can be achieved.

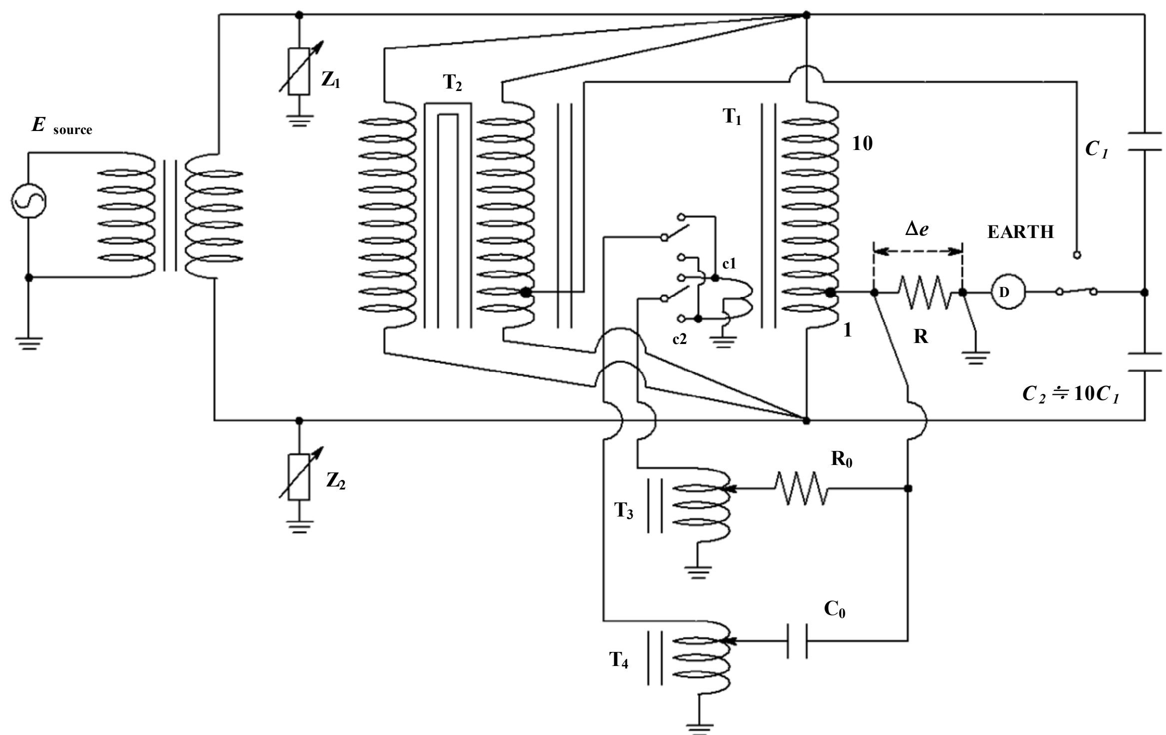

Fig. 2 Circuit diagram of high-precision transformer bridge

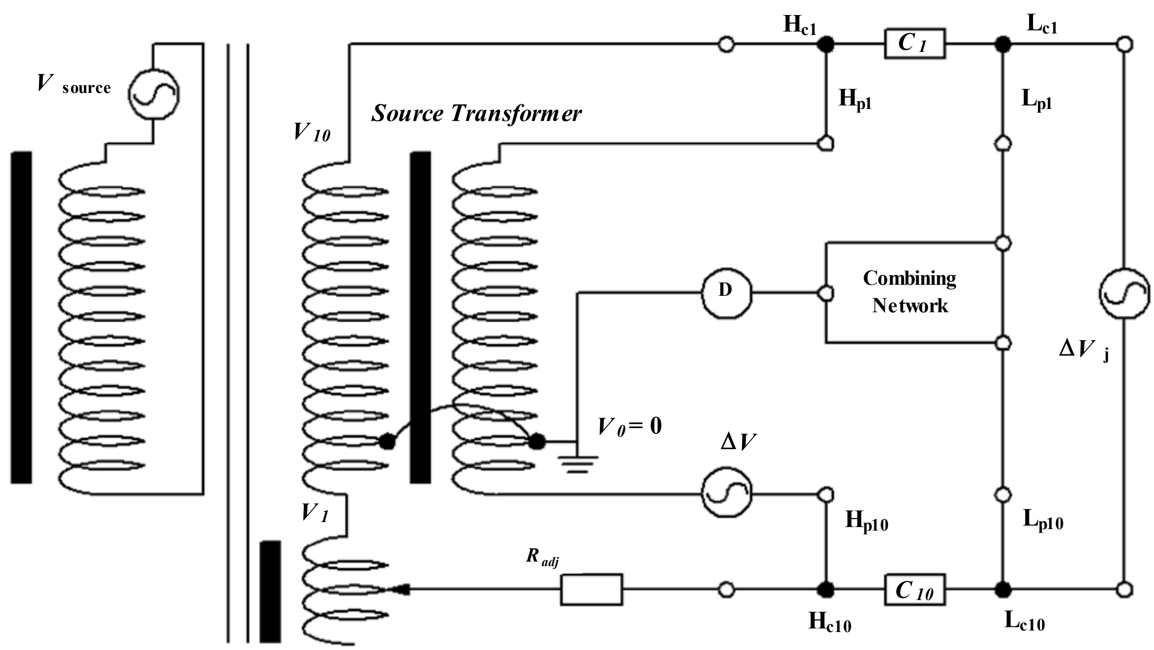

Fig. 3 Circuit diagram of high-precision four terminal-pair capacitance bridge

4. Calibration Service

The high-precision calibration service is achieved using the standard fused-silica capacitors of 10 pF and 100 pF capacitance and a high-precision transformer bridge of 10: 1 ratio for unit under tests (UUTs) of 1, 10, 100, and 1000 pF capacitance.

Table 3 Uncertainty budget of 0.01 μF capacitor at 1 kHz

Source of uncertainty			type	Standard uncertainty (μF / F)
Repeatability (10 data)			A	2
Standard capacitor (0.01 μF)				30.2
	Calibration		B	6.5
	Temperature drift		B	6.0
	Voltage		B	0.6
	Long-term stability (year)		B	28.9
Substitution measurement				9.1
	LCR meter (4284A)			7.1
		Span error	B	0
		Vector rotation error	B	0
		Resolution for WS	B	2.9
		Resolution for UUT	B	2.9
		Changing status	B	5.8
	Coaxial scanner (6022A)		B	5.8
Adapter				0
	Leakage inductance		B	0
	Stray capacitance		B	0
Combined standard uncertainty				31.6
Expanded uncertainty (k=2) (μF / F)				
63.2				
Adopted uncertainty (μF / F)				
70				

A low-cost calibration is achieved by the substitution measurement method[3] for a ratio of 1:1 using the standard ceramic capacitor of the same ratings as UUT, an LCR meter (Agilent Technologies 4284A), and a coaxial scanner (SunJEM 6022A) for UUTs of 100 and 1000 pF, and 0.01, 0.1, 1, and 10 μF capacitance. Fig. 4 shows the connected circuit. The LCR meter has the structure of a coaxial terminal and can be automatically controlled using GPIB. The coaxial scanner with six output terminals consists of the coaxial relay of four terminal-pair, which can be used to measure five capacitors of the same ratings at the same time.

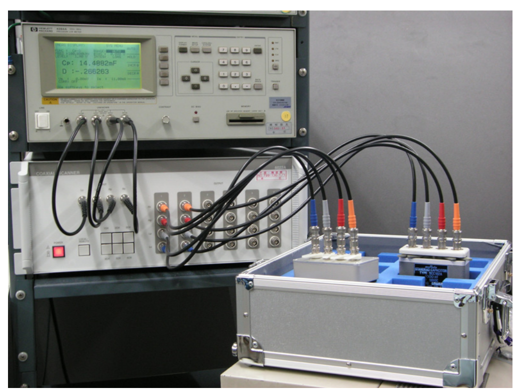

Fig. 4 Connected circuit for LCR meter and coaxial scanner

Table 3 shows an example of the uncertainty budgets (0.01 μF), and shows an example of calibrating a UUT of the same terminal structure as a standard capacitor by the substitution measurement method. If the capacitance values of the standard capacitor and the UUT have a large difference, the span error and the vector rotation error in Table 3 must be considered. The sources of uncertainty are the repeatability of measurements, the uncertainty of the standard capacitor, and the uncertainty of substitution measurement (caused by 4284A and 6022A). If a UUT with a terminal structure different from that of a standard capacitor is calibrated, it is necessary to evaluate the uncertainty caused by the correction of an adapter. Because the greatest source of uncertainty in this budget is the uncertainty caused by the long-term stability of the standard capacitor, a smaller uncertainty will be obtained using an excellent standard capacitor in terms of long-term stability.

5. Conclusion

The calibration system for the capacitance standard in JEMIC was presented in this paper.

The expanded uncertainty at 100 pF is estimated to be 0.73 μF/F (k = 2). On the other hand, the calibration uncertainty using the LCR meter with a coaxial scanner is estimated to be 70 μF/F (k = 2) at 1 kHz.

In the near future, the JCSS calibration will be performed in all the ranges shown in Fig. 1 in JEMIC. Also, the calibration work will be efficiently executed, and lower-cost service will be provided.

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References

1. A. Igarashi, “High Precision Capacitance Comparator for Maintenance of Capacitance Standard”, *JEMIC Technical Report*, Vol.10, No.3, pp.127-134, 1975
2. A. Domae and Y. Nakamura “Calibration of Standard Capacitors of 0.01-1 μF at NMIJ/AIST”, CPEM 2004 Conference Digest (2004)
3. A. Yonenaga and Y. Nakamura “Inductance of Calibration Method Using a Commercial LCR Meter”, CPEM 2004 Conference Digest (2004)