AC-DC TCC with Built-in Tee Connector for Accurate Calibrations

Rasha S. M. Ali

Electrical Quantities Metrology Laboratory, National Institute of Standards (NIS), Egypt

Abstract

Accuracy of thermal current converters (TCCs) calibration to determine their ac-dc differences is important for ac currents measurement traceability. They can be calibrated either by connecting the unknown TCC in series with the standard TCC or connecting them in parallel by using tee connector. In this paper, TCCs are established for this study. One TCC is developed for 5 mA range which consists of only single-junction thermal element (SJTE) with rating 5 mA, 90 Ω. The other TCC is for range 2.5 A constructed from a SJTE connected in parallel with a shunt metal film resistor to withstand its rating current. They are calibrated against standard TCCs by connecting them in series, and in parallel. To overcome some drawbacks in their calibration, a built-in tee connector is also fabricated and introduced in this paper. These built-in tee connectors are connected to the fabricated TCCs to construct built-in TCCs. They are calibrated against the same standard TCCs. Their ac-dc differences are compared to each other. The performances of the TCCs which are calibrated with the different connections are also evaluated by using them in measuring ac currents. The uncertainty budget for the TCCs calibration and the ac currents measurements are estimated.

Keywords: Ac current measurement, Thermal current converter, Ac-dc current transfer difference, Uncertainty.

1. Introduction

Ac voltage and current are considered one of the very important quantities in the electrical field of metrology [1]. Ac current is accurately measured in terms of standard and reference dc current by means of ac-dc TCC to provide traceability to the dc standard. TCCs are mainly made of thermal converters particularly for the milliampere ranges [2]. For higher current ranges, shunt resistors are used to be connected in parallel with the thermal converters. These TCCs are calibrated by using other standard TCCs which are traceable to national metrology institute (NMI) primary standard of ac current. This calibration is done for the accurate determination of the ac-dc current difference which is the metrological factor of TCCs [3]. There are two different methods for calibrating these TCCs where each NMI has its own method. One of them is made by connecting the TCC under calibration and the standard TCC in series. The other is connecting them in parallel by using an external tee connector that is available commercially. For the series connection, the two standards have the same current but there is a problem in grounding [4]. Due to using tee connector in the parallel connection, its admittance can lead to errors in the calibration [5] which increase by increasing the current range and the frequency.

So in this paper to study the effect of the different connections on the TCCs calibration precision and accuracy to improve them, standard TCCs are developed at the National Institute of Standards (NIS), Egypt. The ranges of the fabricated TCCs are 5 mA, and 2.5 A. These standards are automatically calibrated by the two connections against standards TCCs using a LabVIEW program. The introduced TCCs are then connected to the fabricated built-in tee connectors to form built-in TCCs. The construction of these TCCs is introduced at this paper. The fabricated built-in TCCs are also calibrated against the same standard TCCs to verify its behavior. Other TCCs that are calibrated against standard TCCs by series and parallel connections and also calibrated against the fabricated built-in TCCs are then used to measure ac currents at different frequencies. This is made to study the effect of the different calibration systems which are used to calibrate them on the measurement accuracy of the ac currents.

2. Calibration Methods of TCCs

TCCs are established at NIS for this study. One of them consists of SJTE only with rating 5 mA, 90 Ω used as TCC for 5 mA range. The other TCC constructed from a SJTE connected in parallel with a shunt metal film resistor with value 0.2 Ω and power rating 3 W for 2.5 A current range. The used resistor has low inductance value and good stability. These two TCCs can be used from 50% to 120% of their

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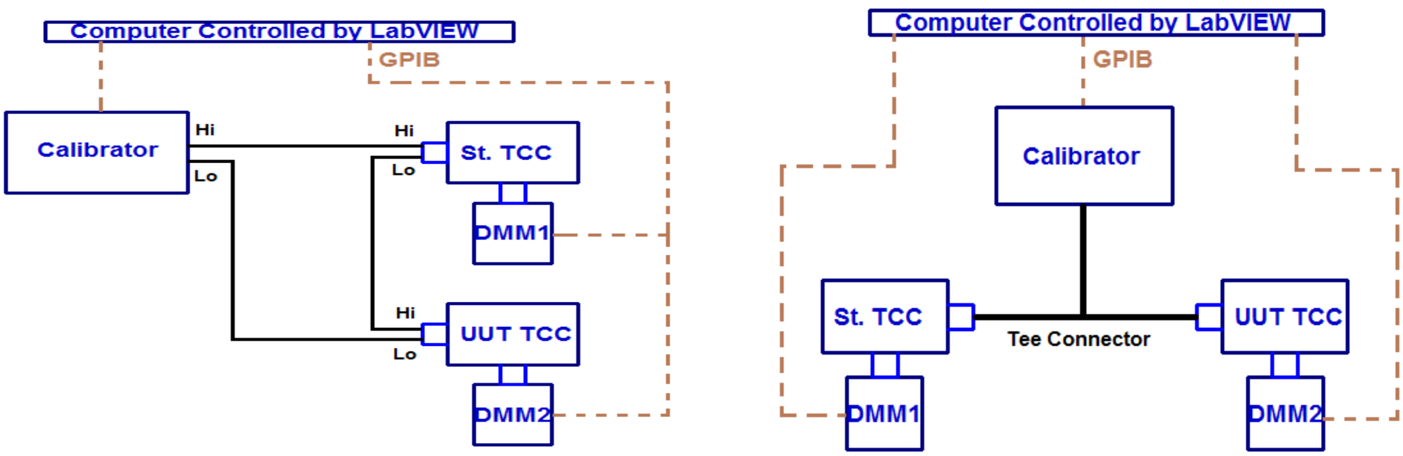
current ratings. They are automatically calibrated by comparison against other standard TCCs which are traceable to PTB, Germany to obtain their ac-dc current difference (δ_c). The unit under test (UUT) TCC and the standard TCC are compared by connecting them in series, and in parallel by using external tee connector. Figure 1 shows the systems set-up for the two connections of the UUT and standard TCCs which are done for calibration. The UUT TCCs are calibrated at frequencies 55 Hz, 300 Hz, 1 kHz, and 10 kHz. The set-up of the calibration systems consists mainly from a calibrator; source of ac and dc currents and two digital multimeters (DMM) to measure the output emfs from the two TCCs. Shielded cables are used for the output emf of the TCCs and connected to the guards of the DMMs to insure the same potential for all the used instruments [4].



(a) Series connection (b) Parallel connection

Figure 1 Set-up of calibration systems for series and parallel connections

The ac-dc difference (δ_c) is obtained from [6]. The results; δ_c and Type A at the different ranges and frequencies by the two connections are compared to each other. Table 1 shows the obtained results for the 5 mA, and 2.5 A TCCs by the series and parallel connections.

Table 1 δ_c and Type A for the fabricated TCCs by the two connections

TCC Range	Connection Method	Obtained Results, µA/A	Frequency (Hz) 55	300	1 k	10 k
5 mA	Series	Ac-dc difference, δ_c	16.2	8.7	1.9	9.8
		Type A	2.6	3.2	4.1	3.2
	Parallel	Ac-dc difference, δ_c	10.4	5.3	3.9	11.6
		Type A	7.0	4.3	5.4	4.1
2.5 A	Series	Ac-dc difference, δ_c	-108	-190	152	91.4
		Type A	5.0	3.7	4.5	5.3
	Parallel	Ac-dc difference, δ_c	-149	-247	165	247
		Type A	8.0	7.4	15	12

It is found that the parallel connection appears higher ac-dc differences and Type A than the series connection especially in the high current at the various frequencies. That is due to the small impedance of the TCC with respect to the tee connector impedance. So, built-in tee connector is developed and studied at this paper.

3. TCC with Built-in Tee Connector

The fabricated TCCs are connected to built-in tee connectors as a trial to overcome the drawbacks of the external tee connector. The introduced connector is mounted on a printed board as shown in Figure 2. The input and one of the output currents terminals are connected to N-type male connectors.

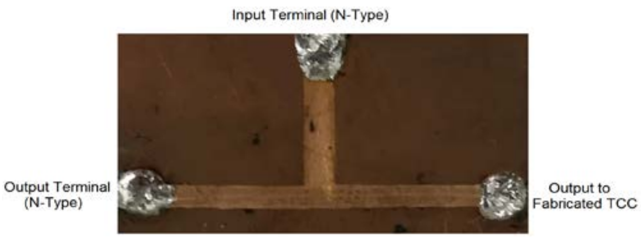


Figure 2 Built-in tee connector

The other output terminal of the introduced tee connector is directly connected to a lead of the fabricated TCCs to be used as standards for the ac current. The other lead of the fabricated TCCs is connected to the low terminal of the input connector to have the same potential. One of the developed built-in tee connector is for the 5 mA, and the other for 2.5 A. The 2.5 A built-in tee connector is constructed to withstand this applied current. They have very small internal impedance with respect to the internal impedance of the external tee connector. These built-in TCCs are calibrated against the same used standard TCCs as shown in Figure 3.

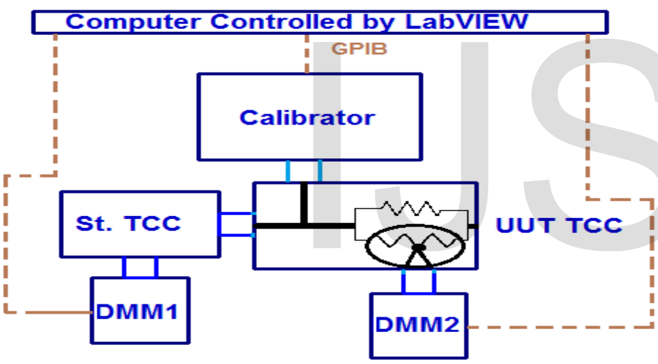


Figure 3 Calibration system by using the built-in TCCs

Figure 4 shows the ac-dc differences of the 5 mA, and 2.5 A fabricated TCCs determined by the different connections; series, parallel, and built-in tee at frequencies 55 Hz, 300 Hz, 1 kHz, and 10 kHz.

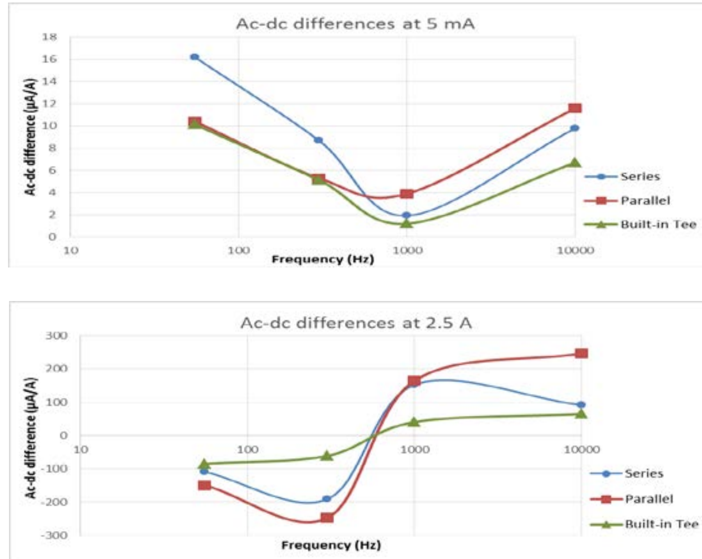


Figure 4 Ac-dc differences of the TCCs obtained by the different connections

The figures illustrate that the built-in TCCs introduces lower ac-dc differences at the different ranges and frequencies particularly in higher current ranges and frequencies. The 2.5 A built-in TCC shows better frequency dependence than the TCCs which are calibrated by other connections. The expanded uncertainty is estimated for the fabricated TCCs calibrations by the different connections according to the GUM; Guide to the Expression of Uncertainty in Measurement [7]. Table 2 demonstrates the uncertainty budget for the calibration of the built-in tee connector TCC 5 mA, 300 Hz as an example.

Table 2 Uncertainty budget for the 5 mA built-in TCC at frequency 300 Hz

Uncertainty Sources	Standard Uncertainty (μA/A)	Probability distribution	Divider	C_i	Degree of Freedom	Uncertainty contribution (μA/A)
Repeatability (12)	0.8	Normal	1	1	11	0.8
Calibration of Standard TCC	3	Normal	2	1	∞	1.5
Calibration of DC Current	10	Normal	2	1	∞	5
Tee Connector Effect	0.87	Rectangular	$\sqrt{3}$	1	∞	0.5
Combined standard uncertainty:						±5.6 μA/A
Effective degrees of freedom:						∞
Expanded Uncertainty at confidence level 95%, (**k = 2**):						±11.2 μA/A

4. Behavior Evaluation of the Introduced TCCs Calibration Methods

The effect of the different calibration connections on the measurement accuracy and the uncertainty of the ac current has been evaluated. Ac currents with values 5 mA and 1.9 A have been measured by other TCCs that are calibrated by the different connections; series and parallel connections, and against the fabricated built-in TCCs. The actual values of the ac currents are obtained from calibrating them at CMI, Czech. The measured values of the ac current by using the TCCs is calculated by [2,8]:

$$I_{ac} = I_{dc}\,(1 + \delta) \qquad (1)$$

Where, I_{dc} is the traceable dc current, $\delta = \delta_m + \delta_c$

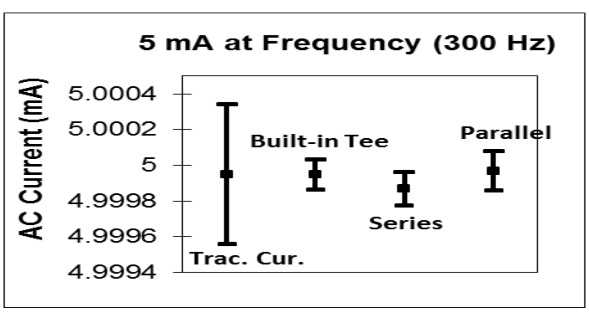
δ_c is the ac–dc current difference of the used TCC, $\delta_m = \dfrac{E_{ac} - E_{dc}}{nE_{dc}}$ (output emfs difference)

Table 3 illustrates the uncertainty budget for the measurement of ac current at 1.9 A, 300 Hz which obtained by using a TCC that is calibrated against the built-in tee connector TCC.

Table 3 Uncertainty budget for the 1.9 A ac current measurement at frequency 300 Hz

Uncertainty Sources	Probability distribution	Divisor	Degree of Freedom	Uncertainty contribution (μA/A)
Repeatability	Normal	1	11	1.6
Standard TCC Calibration	Normal	2	∞	11
DC Current Calibration	Normal	2	∞	8.7
Calibration of DMM	Normal	2	∞	1.7
Resolution	Rectangular	$\sqrt{3}$	∞	1.7×10^{-8}
Thermal emf	Rectangular	$\sqrt{3}$	∞	6
Combined standard uncertainty:				±15.4 μA/A
Effective degrees of freedom:				∞
Expanded Uncertainty at confidence level 95%, **(k = 2)**:				±30.8 μA/A

Figure 5 shows the different results of the 5 mA and 1.9 A ac currents at frequency 300 Hz accompanied with their expanded uncertainties. The results are represented with four error bars.



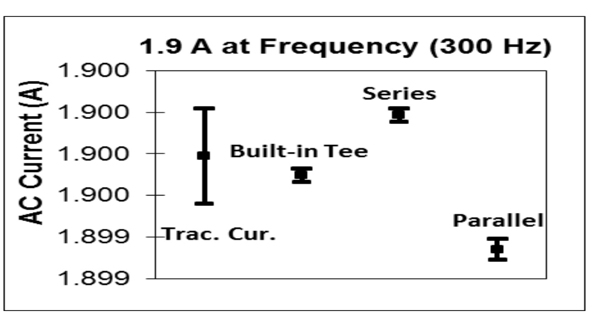


Figure 5 Comparison of ac currents measurements

For the 5 mA TCC, the error bars illustrate that the measured values using the three connections are acceptable and near to the 5 mA actual value especially by using the TCC calibrated by the built-in TCC and also it has a smaller expanded uncertainty. However, the value of the ac current obtained by using the TCC calibrated by the 2.5 A built-in TCC is more accurate than other connections. The obtained value using the calibrated TCC by the series connection is slightly near to the actual value so, it can be accepted. While the value obtained by the TCC calibrated using the parallel connection is so far consequently it is not accepted. It illustrates that at high currents, the built-in TCC is more accurate ac-dc current transfer standard and precise. So, the new fabricated TCCs with built-in tee connector can be considered as a reliable standard for ac currents measurement.

5. Conclusion

To study the effect of the different TCCs calibration connections on the accuracy, TCCs are fabricated and introduced in this paper. Their ranges are 5 mA and 2.5 A.

They are calibrated against other standard TCCs by two different connections; series and parallel using tee connector. The ac-dc differences of the TCCs which are calibrated by using the parallel connection introduce higher values. So, a built-in tee connecter TCC is developed and studied in this paper as a trial to overcome the parallel connection drawbacks done by using external tee connectors. The introduced tee connector is connected directly to the fabricated TCCs to form built-in TCCs. They are used as standards for the 5 mA and 2.5 A ac currents. The built-in TCCs are also calibrated against the same standard TCCs. They demonstrate lower ac-dc differences, and the 2.5 A built-in TCC shows good frequency dependence. The performance of the built-in TCCs is verified by using them as standards to calibrate other TCCs. These TCCs are used in measuring 5 mA, and 1.9 A at 300 Hz. The obtained values are compared with their actual values and also with the results obtained by using the same TCCs which are calibrated again by the series and parallel connections. These comparisons illustrate that the 5 mA TCC which has been calibrated by the different connections has acceptable values specifically when calibrated by the built-in TCC which is near to the 5 mA actual value. While the results obtained by the TCC which has been calibrated by the 2.5 A built-in TCC is more accurate than others. It verifies that the built-in TCC improves the ac current measurement accuracy with reduced expanded uncertainty. Furthermore, the calibration method by the parallel connection is not recommended for the calibration of high ranges TCCs due to the high impedance of the external tee connector compared to the TCCs impedances.

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