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Toward extending the frequency of the AC–DC voltage transfer at Silesian University of Technology up to 10 MHz

Abstract

The paper presents steps taken to extend the frequency range of the thermal AC-DC voltage transfer maintained at SUT up to 10 MHz. The properties of the measurement setup are described after replacing the Fluke 5700A calibrator used as AC voltage source up to 1 MHz with the Fluke 6071A RF signal generator. Next the results of the consistency checking of the AC–DC transfer difference measurements performed with the new measurement setup is presented. The results of verification of the correctness of the calculated and measured AC–DC transfer differences of the two calculable thermal AC voltage standards are presented in 1–10 MHz frequency range. The inconsistency of the measured AC–DC transfer difference is below 55 μV/V at 10 MHz, when comparing PMJTCs with SJTC and below 25 μV/V when comparing PMJTCs among themselves. The AC–DC transfer difference of the SUT calculable AC voltage standard was calculated from the modified mathematical model for frequencies up to 10 MHz. Direct comparison of the 3 V calculable AC voltage standard with the 5 V one confirmed correctness of the results obtained from the mathematical model.

Keywords: AC–DC transfer, AC voltage standard, thermal converter

1. Introduction

In years 2011-2014 team of researchers from Silesian University of Technology (SUT) developed a set of thermal AC voltage standards capable of calibrating thermal voltage converters (TVC) in frequency range from 10 Hz to 1 MHz and from 0.5 V to 1000 V. In the same years a Laboratory of AC–DC Standards was established at SUT. High accuracy of the standards developed at SUT has been confirmed by comparison with foreign primary standards of AC voltage at 1.5 V. The results of this comparison will be published in 2016.

Lately, efforts have been made to extend the frequency of the SUT AC voltage standard up to 10 MHz. These efforts and the most important results of associated investigations are shortly presented in this paper.

2. Modifications in the measurement setup

The AC–DC transfer is performed at SUT in a special measurement chamber with stabilized environment conditions [1]. The measurement setup is composed of the AC voltage source (Fluke 5700A, F5700) [2], the DC voltage source (Fluke 5440B), two DC nanovoltmeters (Keithley 2182A, K2182A) and a custom-made switching-conditioning system MKP-2 [3]. The measurement system is automated and can be controlled and monitored remotely, through Internet. The AC generator (F5700) used currently has no wideband option and can synthesize AC voltage for frequencies up to 1 MHz. So the first step was to find an AC voltage source capable to deliver sufficiently stable AC voltage of frequency beyond 1 MHz. This AC generator should fulfill the following requirements:

- maximum frequency of output voltage above 10 MHz, preferably up to 1 GHz due to some future plans,
- good short-term stability of the output voltage,
- low harmonic distortion of the output AC voltage,
- capability to be remotely controlled through GPIB bus.

After time-consuming investigations, the Fluke 6071A (F6071) radio-frequency signal generator was selected as the new AC generator for performing AC–DC transfer comparisons at frequencies above 1 MHz [4]. It could synthesize a sinusoidal AC voltage in frequency range from 200 kHz to 1040 MHz. Its maximum output power is 19 dBm below 520 MHz and 13 dBm at higher frequencies. The generator is equipped with an N-type output connector and has GPIB interface.

The features of the new measurement setup was verified by performing comparisons of the TVCs in 200 kHz - 1 MHz frequency range and at 1 V. Two Planar Multijunction Thermal Converters (PMJTC) of nominal input voltages 1 V and 2 V were used in this measurement, but in the first comparison the F5700 AC voltage source was used while in the second the F6071 one. Measured differences between AC–DC transfer differences of the two compared TVCs are presented in Fig. 1. A very good agreement between results confirmed, that the replacing the F5700 with F6701 had not introduced any additional error.

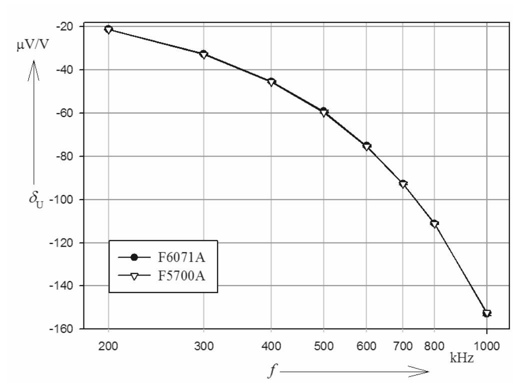

Fig. 1. Differences of AC – DC transfer differences of the two PMJTCs measured using different AC voltage sources

Duration of the AC–DC transfer as well as its accuracy depends on, among the others, a number N_{DC} of corrections of the DC voltage during the AC–DC transfer procedure. In the new setup the value of N_{DC} is much higher than in the old one, which used Fluke 5700 (Tab. 1).

Tab. 1. Typical number N_{DC} of corrections of DC voltage required during comparison two PMJTCs for different AC voltage sources

Frequency	Type of the AC voltage generator	
kHz	F6071	F5700
200	3	1
300	4	1
400	2	1
500	3	1
600	2	1
700	2	1
800	4	1
900	3	1
1000	3	1

Several attempts to minimize the N_{DC} were made, including turning off the output of the AC generator or reducing the frequency of the AC voltage when DC voltage was applied to TVC inputs. Unfortunately, none of these methods reduced the number of the necessary DC voltage corrections. Contrary, these methods increased the A-type uncertainty of the measured AC–DC transfer differences. The additional DC voltage corrections are most probably caused by worse stability of the F6071 output voltage in comparison with the stability of the F5700.

3. Consistency of AC–DC transfer difference measurements performed with the new measurement setup

The correctness of the AC–DC transfer difference measurements performed with the F6071 generator was verified using a well-known method of triangle measurement consistency check. The result is presented in Fig. 2.

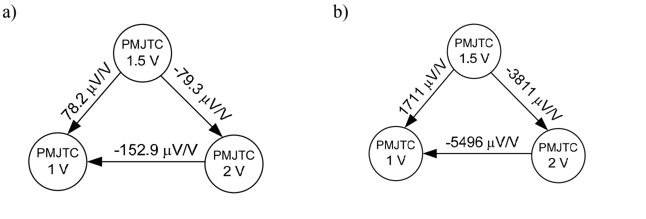

Fig. 2. Consistency check of AC-DC comparisons of the three PMJTCs: a) at 1 MHz, b) at 10 MHz

At 1 MHz (Fig. 2a) the inconsistency of measurements of AC–DC transfer difference, obtained when using the F6071A as AC voltage generator, is approximately 5 µV/V. The combined uncertainty of each measurement at 1 MHz was in the order of 1 µV/V. At 10 MHz (Fig. 2b) the inconsistency increased to approximately 26 µV/V. The combined uncertainty of AC–DC transfer difference measurement at 10 MHz was approximately 16 µV/V.

All TVCs used in the measurements from Fig. 2 were PMJTC of PTB/IPHT design [5]. However, the SUT's calculable AC voltage standards [6] use single junction thermal converters (SJTC), which have lower output resistance and lower parasitic capacitance between the heater and the thermocouple. Especially the last leads to specific systematic error reported in [7]. Therefore it was necessary to perform a consistency check for AC-DC comparisons of PMJTCs and SJTCs too. The results are shown in Fig. 3.

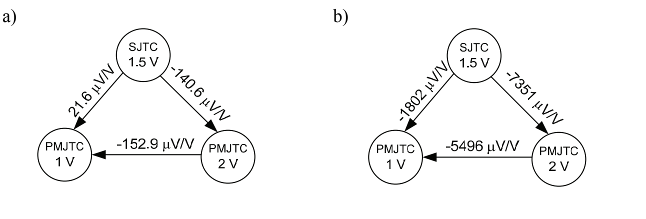

Fig. 3. Consistency check of AC-DC comparisons of PMJTCs and a SJTC: a) at 1 MHz, b) at 10 MHz

At 1 MHz (Fig. 3a) the inconsistency of measurements of AC–DC transfer differences, obtained when using the F6071 as the AC voltage generator, is approximately 9 µV/V, i.e. higher than that obtained for the comparison of three PMJTCs shown in Fig. 2. Nevertheless, the obtained values are close to results obtained when using the F5700 as AC voltage generator [8]. At 10 MHz (Fig. 3b) the inconsistency increases to approximately 52 µV/V. The combined uncertainty of AC-DC transfer difference measurement at 10 MHz was approximately 23 µV/V.

4. The AC–DC transfer difference of the SUT calculable AC voltage standard

The AC–DC transfer difference of a TVC is usually measured in a comparison process with another TVC with a known value of this parameter. In the case of TVCs used in primary AC voltage standard, their AC–DC transfer difference is calculated using a suitable mathematical model [9]. Accordingly the AC–DC transfer difference of two TVCs maintained at SUT was calculated in 10 kHz - 1 MHz frequency range [6]. Input parameters for this model are material constants and geometrical dimensions of the TVC.

Correctness of the mathematical model of the SUT AC voltage standard was verified using the following two methods:

- by comparison of differences between calculated and measured AC–DC transfer differences of the two calculable TVCs of different nominal input voltage, dimensions and radius of the resistive wire used as series range resistor [6];
- by calibrating the SUT calculable AC voltage standard with a "travelling" standard TVC, commercially calibrated in an external laboratory.

The both methods confirmed the correctness of the calculation of the AC–DC transfer differences of the SUT AC voltage standards at 10^{-6} V/V level of standard uncertainty up to 1 MHz [6].

The mathematical model used at frequencies up to 1 MHz was used to calculate the AC–DC transfer differences in 1–10 MHz range. The calculated AC–DC transfer differences of the both calculable SUT AC voltage standards are shown in Fig. 4.

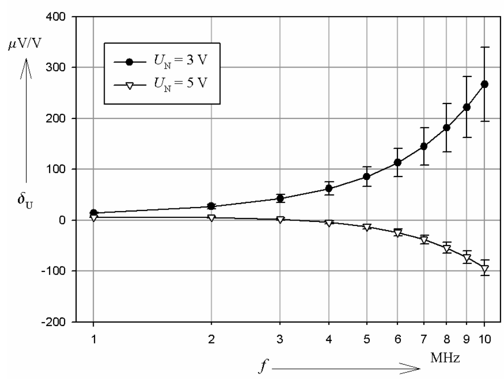

Fig. 4. Calculated AC – DC transfer difference of the two SUT calculable AC voltage standards in frequency range from 1 MHz to 10 MHz

The AC–DC transfer difference of the 3 V standard is monotonically raising to positive values and reaches 267 µV/V at 10 MHz. The calculated AC–DC transfer difference of the 5 V standard is positive below 3 MHz, then it changes its sign to negative and decreases reaching -93 µV/V at 10 MHz. The maximum positive value of the AC–DC transfer difference of this standard is 5.6 µV/V at 1 MHz.

The uncertainty of the calculated AC–DC transfer differences shown in Fig. 4 was estimated using mathematical model and Monte Carlo method. The uncertainty budget includes influence of all materials constants and geometrical dimensions of the standard. The influence of solder joints impedances was estimated using a modified standard TVC. The associated uncertainty was estimated from the following approximation functions [8]:

$$u(\delta_{U=3V}) \approx 0.3 \cdot 10^{-6} f + 0.09 , \qquad (1)$$

$$u(\delta_{U=5V}) \approx 0.03 \cdot 10^{-6} f + 0.007 . \qquad (2)$$

The uncertainty of the calculated AC–DC transfer difference of the SUT AC voltage standards is quite small in comparison to their AC–DC transfer differences. At 10 MHz the uncertainty of the calculated AC–DC transfer difference of the 3 V standard (73 µV/V) is higher than that of the 5 V standard (16 µV/V).

The influence of the most important parameters on the estimated total B-type standard uncertainty of the both calculable SUT AC voltage standards at 10 MHz is presented in Table 2. The biggest influence on the uncertainty of the calculated AC–DC transfer difference of the SUT AC voltage standards has the uncertainty of electrical conductivity of the resistive wire of the series resistor, which was used to increase the nominal input voltage of the standard. The uncertainty of the other parameters of this wire (radius and length) also substantially influence the total B-type uncertainty of the calculated AC–DC transfer difference of these standards.

Tab. 2. Influence of the uncertainty of determination of selected parameters on the estimated total B-type standard uncertainty of the AC-DC transfer difference of SUT AC voltage standards at 10 MHz

Parameter	$u(\delta_U)$ (µV/V)	
	U_N = 3 V	U_N = 5 V
Conductivity of the resistive wire	65.4	13.9
Radius of the resistive wire	29.4	6.3
Length of the resistive wire	-1.9	-1.3
Resistance of the SJTC heater	-12.9	-1.0
Length of leads of the SJTC	1.8	-0.9
Length of the SJTC heater	1.8	-0.6
Radius of the SJTC copper leads	-5.8	-2.3
Length of the SJTC copper leads	1.5	0.7
Variation of impedance of solder joints	3.1	0.3
Total uncertainty	73.2	15.5

The correctness of calculated values of the AC–DC transfer difference of the standards was verified empirically by their direct comparison. Comparison of calculated and measured differences of AC–DC transfer differences of these standards is presented in Fig. 5.

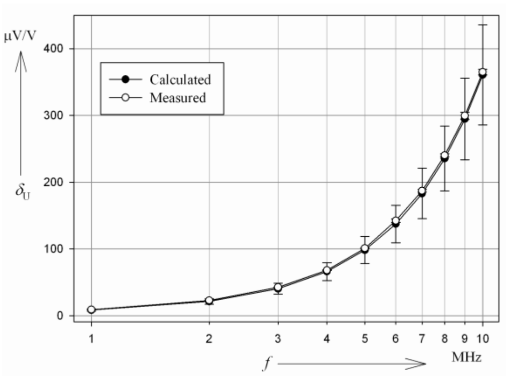

Fig. 5. Calculated and measured differences of the AC – DC transfer difference of the two SUT calculable AC voltage standards in frequency range from 1 MHz to 10 MHz

Due to the limited output power of the F6071 generator, the comparison was performed at lower input voltage (U_{IN} = 2.5 V) what resulted in lower output voltage of the standards and increased A-type uncertainty. Nevertheless, the difference between measured and theoretically calculated differences of the AC–DC transfer differences was lower than combined standard uncertainty of these measurements. The biggest difference was obtained at 8 MHz and was below 5 µV/V. The comparison presented in Fig. 5 partially confirmed the correctness of the mathematical model of the both SUT calculable AC voltage standards. However, to fully confirm the correctness of the mathematical model as well as measurement results obtained with the modified measurement setup an interlaboratory comparison should be performed.

5. Summary

The modified measurement setup, with the F5700 AC voltage source replaced by the F6071 RF signal generator, allows to calibrate TVCs at frequencies up to 10 MHz. Unfortunately the output power of the F6071 is insufficient to perform AC–DC measurements at AC voltages higher then approximately 2.5 V. Nevertheless, the differences of the AC–DC transfer differences, measured with the both AC voltage sources below 1 MHz are small and lower than the standard uncertainty of these measurements. The triangle measurement consistency check shows, that the measured AC–DC transfer difference is below 55 µV/V at 10 MHz, when comparing PMJTCs with SJTC and below 25 µV/V when comparing PMJTCs among themselves. Direct comparison of the 3 V calculable AC voltage standard with the 5 V one confirmed correctness of the results obtained from the mathematical model of the SUT calculable AC voltage standard up to 10 MHz. The difference between the calculated and measured AC–DC transfer differences was lower than the combined standard uncertainty of the measurement. To obtain another confirmation of the correctness of the obtained results an interlaboratory comparison of the thermal AC voltage standards at voltage from 2 V to 3 V and in 1 – 10 MHz frequency range is planned for 2016.

6. References

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