Automatic determination of the Thin-Film Multijunction Thermal Voltage Converter parameters

R. S. M. Ali
National Institute for Standards (NIS), Egypt

Abstract

The Thin Film Multijunction Thermal Converter (TFMJTC) has become the most sensitive and precise transfer standard for the accurate measurement of the ac quantities. Therefore, its parameters are determined at the National Institute of Standards (NIS), Egypt, to obtain its best operating conditions. These parameters are short-term stability, settling time, dc response time, n-factor, input/output dc curve and frequency response. All these parameters are determined automatically by using LabVIEW programs. From the results, it is found that the TFMJTC stabilizes at time 50 sec. At this time it has accepted short-term drifting error, 29 ppm, which can be considered its settling time. It is also shown that the 5 sec. is the response time of the TFMJTC. It is also shown that the practical response of the TFMJTC is according to the square-law at the test voltage from 40% to 100% of the rated voltage and the ac voltage is converted to the output dc voltage in a true square-law response with negligible deviation from the theoretical results. It can therefore be used successfully in these test voltages. The TFMJTC has lower uncertainty in calibrating the ac signals.
Keywords: AC-DC transfer standard, Thin Film Multijunction Thermal Converter, AC voltage calibration.

1 Introduction

The ac voltage is most accurately measured by comparison with dc voltage using thermal voltage converter (TVC) which respond nearly equal to ac and dc voltage. Alternating and direct voltages have the same effective amplitude when they produce identical amounts of power in a pure resistive element [1]. This power is dissipated as heat. According to Joule's law, the heat radiated by the

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resistor is proportional to the power produced in the resistor. This heat is measured by sensors which its input responds directly to temperature and its output yields a dc emf that is proportional to this heat. This kind of sensor is called thermal-elements [1]. When the difference between V_{ac} and V_{dc} is small, the proportional difference can be computed from eqn (1) [2]:

$$\frac{V_{a.c} - V_{d.c}}{V_{d.c}} = \delta_m + \delta_c = \delta_n \tag{1}$$

where, δ_m is the difference between the thermocouple output

$$\delta_m = \frac{E_{a.c} - E_{d.c}}{nE_{d.c}} \tag{2}$$

δ_c is the ac – dc difference correction of the TVC which determined by comparing it to a similar standard instrument whose correction is known.

Then,

$$V_{ac} = V_{dc}\,(1 + \delta_n). \tag{3}$$

Today, there are a number of different design models and different ways of ac-dc thermal transfer standards in use. But the TFMJTC becomes the most sensitive and accurate standard for the precise measurement of electrical ac quantities in the frequency range of 10 Hz–1 MHz. The TFMJTC consists of bifilar heater with very low resistance and small Thomson and Peltier coefficients. It also consists of 100 thermocouples (Cu-CuNi 44) which evaporated on a thin dielectric sandwich membrane covering a window etched into a silicon chip [3]. The hot junctions of the thermocouple array are distributed along the heater and the cold junctions are arranged symmetrically on the silicon acting as a heat sink. The advantages of the TFMJTC are that it has very small ac-dc differences, high output emf (in the range of 100 mV), cost reduction and high sensitivity due to low thermal conductance of the thin dielectric membrane and thermocouple system. In the other hand, the TFMJTC has disadvantages such as high output resistance, high output ac noise level and low insulation between input and output at higher frequencies [4].

2 Practical determination of the parameters

There are many parameters for the TFMJTC are measured automatically by using LabVIEW program. 2-V range TFMJTC is used as an example. The results are saved automatically in an excel sheet. The These measurements are done in environmental conditions of temperature (23 ± 1)°C and humidity (60 ± 10)% HR. The determined parameters are short-term stability, settling time, dc response time, n-factor, input/output dc curve and frequency response.

For the short-term stability test, the stability of the output emf for the TFMJTC is studied during 3 minutes to determine the settling time of it. The settling time is the time it takes for the transfer standard output to stabilize after a voltage is applied to the input [1] and has accepted drifting error from the steady state output voltage. The drifting error, D.E, in ppm can be obtained from [5]:

$$\text{D.E} = \frac{E_s - E_i}{E_s} \text{ x } 10^6 \tag{4}$$

where, E_s is the steady state output emf after 3 minutes.

E_i is the output emf at each 10 sec.

Table 1 and Figure 1 show the short-term drifting error and the excel sheet of it respectively. It is found that the short-term drifting error is reduced with time from 7% to 2 ppm at 3 minutes. At time 50 sec., the TFMJTC has accepted drifting error, 29 ppm and it can be considered its settling time and the enough time for waiting before recording the output emf.

Table 1: The short-term drifting error for the TFMJTC.

Time (sec.)	Output emf (mV)	Relative Drifting Error (ppm)
10	91.647763	73025
20	95.853359	30487
30	97.861329	10178
40	98.76387	1049
50	98.864724	29
60	98.865238	24
70	98.865168	24
80	98.865254	23
90	98.865397	22
100	98.865720	19
110	98.865832	18
120	98.865946	17
130	98.866361	13
140	98.866582	10
150	98.867006	6
160	98.867404	2
170	98.867616	0

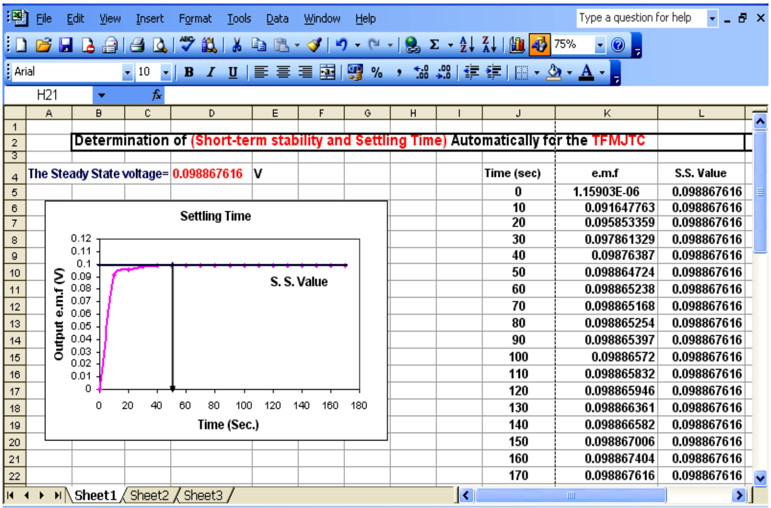

Figure 1: Excel sheet of the TFMJTC settling time.

The dc response time of it is also determined. It is defined as the time taken for the output of the thermocouple to rise to 1- $^1/_e$ (approximately 63%) of its final value when the heater voltage is switched on [6]. So, 63% of the TFMJTC steady state value is about 62.48 mV. Figure 2 shows the excel sheet of the TFMJTC response time. It is found that the 5 sec. is the response time of the TFMJTC.

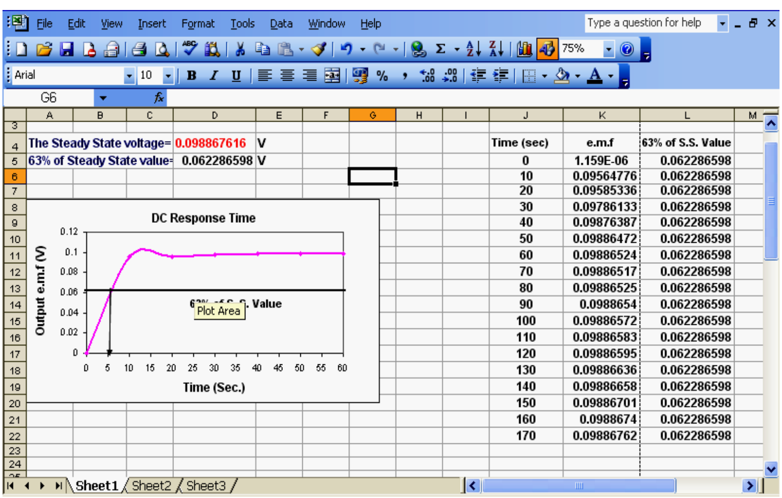

Figure 2: Excel sheet of the TFMJTC response time.

Factor n test is one of the important tests that are readily performed practically and automatically. Where the relationship of the output emf, E, to the heater voltage, V, may be expressed as:

$$E = kV^n \tag{5}$$

The factor k varies somewhat with large changes in heater current and is constant over a narrow range where nearly equal ac and dc currents are compared.

The relationship between a small change in TE heater voltage (ΔV) and the corresponding change in output (ΔE) is expressed as [7]:

$$\frac{\Delta V}{V} = \frac{\Delta E}{nE} \tag{6}$$

Then,

$$\text{Factor n} = \frac{(\Delta E / E)}{(\Delta V / V)} \tag{7}$$

where, V is the nominal applied voltage to the TFMJTC, E is the output emf at the nominal applied voltage and ΔE is the change in the output emf due to change in the applied voltage ΔV. Figure 3 shows the excel sheet of the n-factor.

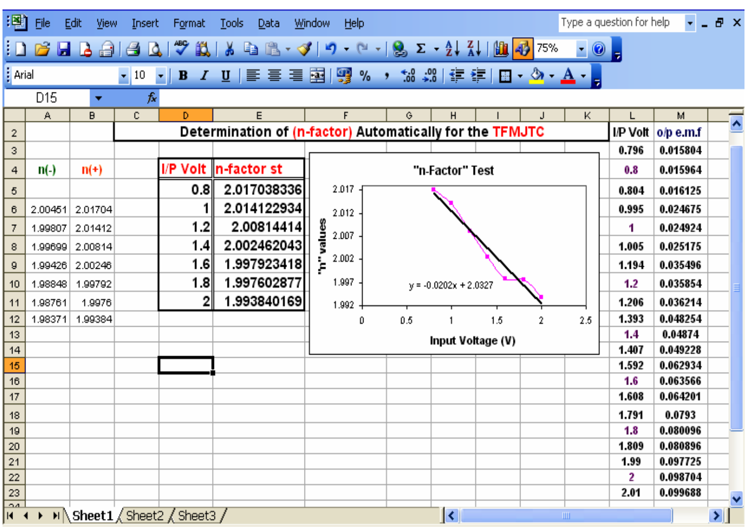

Figure 3: Excel sheet of the n-factor test.

It is shown the values of "n" for the test voltage from 40% to 100% of the rated voltage where each value of n is calculated as the average of two values ($V \pm 0.5\%$ of V) to give ΔV at each test voltage [8]. The results indicate that the value "n" of the TFMJTC at the different test voltages is nearly equal to 2.

The input/output curve was tested to the TFMJTC to assure the response of it to the square law. The deviation from the square law can be calculated from the difference between the calculated values of the emf at certain input voltage (theoretical results) and the measured values of the output emf (practical results). The output emf is calculated theoretically for n=2; from the relation $E=kV^2$ where $k= E/V^n$ (V is the rated voltage, E is the output emf at the rated voltage and n is the factor n at the rated voltage); for each applied voltage. Then k is equal to 0.025. Table 2 shows the practical results and the theoretical results of the output emf for the TFMJTC.

Table 2: Practical and theoretical results for the TFMJTC.

Practical results		**Theoretical results**	
Applied Voltage (mV)	Output emf (mV)	Applied Voltage (mV)	Output emf (mV)
0.8	15.964	0.8	16
1	24.924	1	25
1.2	35.854	1.2	36
1.4	48.74	1.4	49
1.6	63.566	1.6	64
1.8	80.096	1.8	81
2	98.704	2	100

Figure 4 shows the excel sheet of the practical and theoretical results. It is shown from the curve that the practical response of the TFMJTC is according to the square-law and the ac voltage is converted to the output dc voltage in a true square-law response with negligible deviation from the theoretical results.

Frequency dependence for the TFMJTC is also determined automatically. It is defined as the change in the ac-dc difference with a change in frequency of 1 Hz [5]. Figure 5 shows the excel sheet of the ac-dc differences of the TFMJTC at different frequencies.

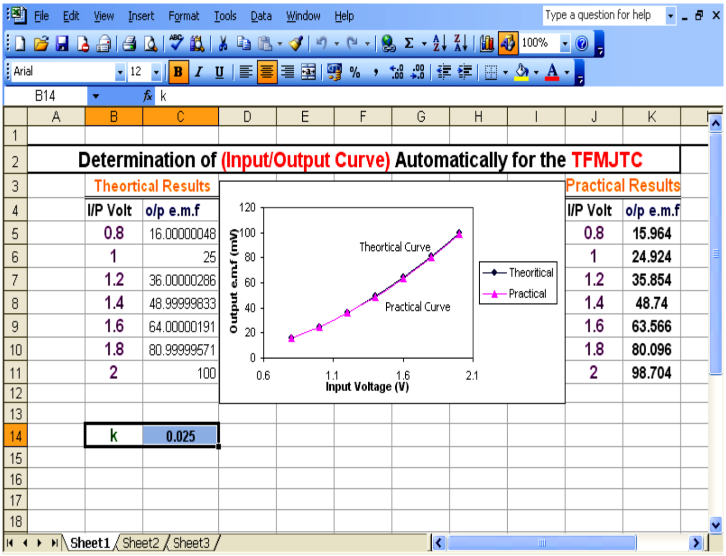

Figure 4: Excel sheet of the input/output dc curve.

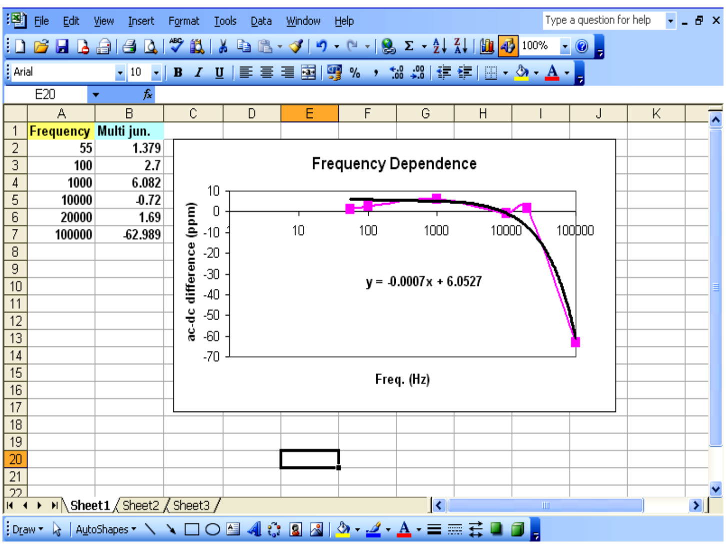

Figure 5: Excel sheet of the TFMJTC frequency dependence.

The uncertainty budget is evaluated for the ac-dc differences of the TFMJTC [9]. The sources of uncertainty are the repeatability (Type A) which is computed for 13 values and Type B that has many contributions such as TVC calibration, DC source calibration and temperature change. Table 3 shows the uncertainty budget of the 2 V at 1 kHz as an example.

Table 3: Uncertainty budget for 2 V at 1 kHz.

Uncertainty sources	Probability distribution /method of evaluation	Uncertainty values, ppm
Type A	Normal/A	0.14
TVC Calibration	Normal/B	0.5
DC Source Calibration	Normal/B	0.21
Temperature Change	Rectangular/B	negligible
Expanded uncertainty, (k = 2)		±1.11 ppm

Table 4 shows the expanded uncertainty (k=2) of the TFMJTC ac-dc differences at different frequencies 55 Hz, 100 Hz, 1 kHz, 10 kHz, 20 kHz and 100 kHz.

Table 4: Results of expanded uncertainty at different frequencies.

Frequency (kHz)	Exp. uncertainty ± ppm
0.055	1.35
0.1	1.32
1	1.11
10	1.31
20	1.12
100	3.06

3 Conclusion

The TFMJTC becomes now the most sensitive and precise transfer standard for the accurate measurement of the ac quantities. Therefore, its parameters are determined to obtain its best operating conditions. From the results, it is found that the TFMJTC stabilizes at time 50 sec. because at this time it has accepted short-term drifting error so it can be considered its settling time and the enough time for waiting before recording the output emf. It is also shown that the 5 sec. is the response time of the TFMJTC. It responses better to the square law, nearly equal to 2 at the test voltage from 40% to 100% of the rated voltage and the practical response of the TFMJTC is slightly deviated with negligible differences from the theoretical results. So it can be used in all voltages from 40% to 100% of the rated. The TFMJTC has lower Uncertainty in calibrating the ac signals.

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