Comparison of two different methods to build micropotentiometers for low-voltage AC-DC transfer

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Abstract. This paper shows a comparison between two different approaches to build micropotentiometers (µpots) for AC-DC transfer measurements at low voltages. An overview of µpots is presented, and two different approaches to build them are introduced. Two µpots built using the different approaches are compared using a calibrated thermal transfer standard, and the results are presented and discussed.

1. Introduction
In the past, AC-DC low voltage calibration (2 mV to 100 mV) was performed at Inmetro using a commercial thermal transfer standard traceable to another National Metrology Institute (NMI) [1]. In the last few years we started the implementation of a new system, using micropotentiometers (µpots). Two different approaches were adopted: a µpot using a Planar Multijunction Thermal Converter (PMJTC) [2] and a disk resistor (in-house built) [3, 4] and a “discrete µpot” [5], using commercial current shunts as output resistors. In this paper we present an overview of the two technics and compare the obtained results.

2. Micropotentiometers
The electrical circuit of a µpot, using a PMJTC as the thermal converter, is presented in figure 1.

The device should work up to 1 MHz, so the output resistor should have a nearly flat frequency response up to that value. It is important, also, that its resistance value be small, to reduce
the loading when connecting to a device with a finite input impedance [6]. Note that the input voltage \( V_{in} \) must be calculated in function of the \( \mu \)pot parameters to obtain the desired voltage at the output \( V_{out} \).

![Figure 2. Disk resistor \( \mu \)pot.](image)

![Figure 3. Discrete \( \mu \)pot.](image)

According to the circuit shown in figure 1, the output voltage of the \( \mu \)pot is given by equation 1 and the voltage applied to the PMJTC is given by equation 2.

\[
V_{out} = \frac{V_{in}R_o}{R_1 + R_{pmjtc} + R_o}
\]

\[
V_{pmjtc} = \frac{V_{in}R_{pmjtc}}{R_1 + R_{pmjtc} + R_o}
\]

The PMJTC used has a nominal heater resistance of 90 \( \Omega \), and is rated for a nominal input voltage of 1 V. The values of the input resistor \( (R_1) \) and the output resistor \( R_o \) need to be chosen to satisfy two main conditions: when the output voltage is the nominal voltage of the \( \mu \)pot, \( V_{pmjtc} \) should not exceed the maximum rating of the PMJTC; and when \( V_{out} \) is at the minimum working value, \( V_{pmjtc} \) need to be sufficient for a satisfying measurement of \( E_{out} \).

For this work, a \( \mu \)pot for the range from 20 mV to 100 mV will be designed. Two different approaches to implement the output resistor \( (R_o) \) will be explored: (a) building a disk resistor by soldering SMD resistors on a disk-shaped PCB and (b) using a commercial current shunt.

The \( \mu \)pot using a disk resistor is shown in figure 2. \( R_1 \) is a thin-film resistor of 500 \( \Omega \), and the disk resistor was built using several SMD resistors in parallel. The nominal value of the disk resistor is 10 \( \Omega \). The housing is a brass rectangular box, with female N-type connectors for input and output.

The discrete \( \mu \)pot uses the same base circuit shown in figure 1, with only one difference: the output resistor, \( R_o \), is a commercial current shunt. For the range from 20 mV to 100 mV, the current shunt used has a nominal resistance of 8 \( \Omega \). The housing of the discrete \( \mu \)pot was built using a brass cylinder, with N-type connectors. A thin-film resistor of 500 \( \Omega \) was connected in series with a 90 \( \Omega \) PMJTC. The discrete \( \mu \)pot can be seen on figure 3.

Table 1 shows the relations calculated by equations 1 and 2 and the output resistance for the built \( \mu \)pot.
Table 1. Electrical specifications for the \( \mu \)pots.

| \( \mu \)pot  | \( V_{out}/V_{in} \) | \( V_{pmjtc}/V_{in} \) | \( R_{o}[\Omega] \) |
|------------|------------------|-----------------|----------------|
| disk resistor | 0.0166 | 0.150 | 10 |
| discrete    | 0.0134 | 0.150 | 8  |

Table 2 shows the needed input voltage to obtain the maximum (100 mV) and minimum (20 mV) output voltages designed for the \( \mu \)pots. The voltage applied to the PMJTC (\( V_{pmjtc} \)) in both cases is shown, also.

Table 2. Input and output voltages.

| \( \mu \)pot  | \( V_{in} [V] \) | \( V_{out} [mV] \) | \( V_{pmjtc} [V] \) |
|------------|-----------------|-----------------|----------------|
| disk resistor | 6.02 | 100 | 0.90 |
|             | 1.20 | 20 | 0.18 |
| discrete    | 7.46 | 100 | 1.12 |
|             | 1.49 | 20 | 0.22 |

3. Results

The \( \mu \)pots were measured against a calibrated commercial thermal standard. The measurement setup using the disk resistor \( \mu \)pot is shown on figure 4, and the measurement system using the discrete \( \mu \)pot can be seen on figure 5.

![Figure 4. System with disk resistor \( \mu \)pot.](image1)

![Figure 5. System with discrete \( \mu \)pot.](image2)

For each frequency, 12 measurements were made. The results for the disk resistor \( \mu \)pot and for the discrete \( \mu \)pot, corrected with the AC-DC difference of the standard, are presented in table 3.
Table 3. Measured AC-DC differences in µV/V.

| f [kHz] | 0.01 | 0.065 | 1   | 10  | 100 | 1000 |
|---------|------|-------|-----|-----|-----|------|
| Disk resistor µpot | 60 mV | 17    | 18  | -3  | -1  | 17   | 85  |
| Discrete µpot      | 20 mV | 2     | 17  | -8  | -1  | 14   | 82  |

Table 4. Expanded uncertainties in µV/V.

| f [kHz] | 0.01 | 0.065 | 1   | 10  | 100 | 1000 |
|---------|------|-------|-----|-----|-----|------|
| 60 mV   | 35   | 23    | 23  | 23  | 28  | 81   |
| 20 mV   | 51   | 26    | 25  | 26  | 32  | 85   |

The expanded uncertainties are presented in table 4.

4. Conclusions
The stability of the measurements using both µpot is similar. For 60 mV, the standard deviation of the 12 measurements for each frequency was around 1 ppm. For 20 mV, the standard deviation was around 5 ppm.

The disk resistor µpot has smaller AC-DC difference for high frequencies than the discrete µpot, as can be seen on tables 3 and 4. But, on the other hand, the discrete µpot is easier to be built, and a good connection between the output resistor and the rest of the system is guaranteed by the N-type connector. In the case of the disk resistor µpot, this connection is more difficult to be made, especially between the outer part of the disk and the housing (figure 2).

The results show that both approaches have similar results, with the advantage of easier construction for the discrete µpot.

References
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