THE METROLOGIST'S CLOCK

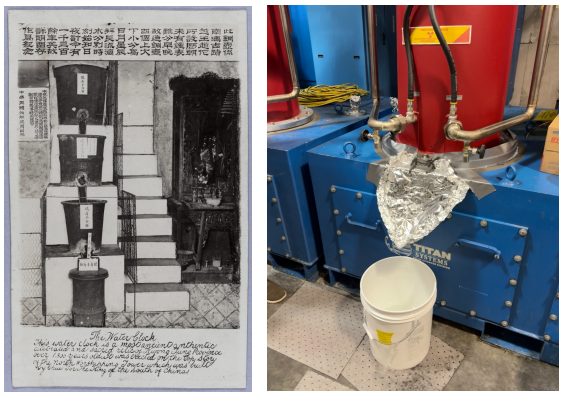
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Time, as both a physical and a philosophical quantity, is a continuum in which all processes take place. Time measurement has undergone a long evolution—from counting sunrises to atomic clocks. This article concerns the design and metrological characterisation of a time-measuring instrument—a clock—in the context of personnel and a laboratory for DC electrical metrology.

1. INTRODUCTION

A watchmaker is a qualified specialist who understands the mechanics of precision timepieces and can diagnose and repair various problems with clock mechanisms. An electrical metrologist, by contrast, has no understanding of the mechanics of precision timepieces and cannot design, diagnose, or repair a clock mechanism. A metrologist nevertheless needs to know when to go to lunch or when to leave the workplace, and to know this with extremely low uncertainty.



a) *b)*

Fig. 1: Water clocks: a) implementation of the clepsydra [1], China, 1324 AD; b) implementation at a scientific laboratory, USA, 2024 AD.

The best metrology institutes have sophisticated instruments for measuring time [2]. In the time department of the national institute in the Karlova Ves area, for example, there is a bucket in the middle of the room into which water drips.

Not all metrology institutes can afford such advanced equipment, however. But every institute has sources of 'mlun' or various multimeters. An old saying goes: if the only tool you have is a hammer, every problem looks like a nail. This leads us to the idea of using 'mlun' voltage to display the time. The idea is not new at all. On the interwebs, we can find 2,660,000 literary sources on the subject of voltmeter clocks. A typical implementation is shown, for example, in Fig. 2.



Fig. 2: An example of voltmeter clocks, very popular among hobbyists [4].

Although such clocks look attractive, their practical value is minimal. The analogue pointer indicators have an unknown accuracy class; their linearity is unknown, and no measurement report can be produced from the readings. Such practices are unthinkable in any reputable metrology laboratory.

The Dúbravský Metrology Institute sets trends, so we set about developing the Metrologist's Clock, which does not suffer from any of the problems mentioned above.

2. THE CLOCK

The Metrologist's Clock developed at DMI takes a different approach. Time is represented by a DC voltage, U_OUTPUT, in the range from 0.0000 V to 23.5959 V, according to the following equation:

$$U_{OUT} = H \times 1{,}0000\,\frac{V}{hour} + M \times 0{,}1000\,\frac{V}{min} + S \times 0{,}0010\,\frac{V}{sec}, \qquad (1)$$

where H is the current hour, M is the current minute, and S is the current second. U_OUTPUT is measured, preferably, using a Fluke 8588A reference multimeter, or alternatively an HP/Agilent/Keysight 3458A (depending on which week the multimeter was purchased).

Equation (1) is implemented by a 20-bit AD5791BRUZ digital-to-analogue converter with excellent linearity. The ADR1001 integrated circuit is used as the reference source for midnight (23:59:59). The approximately 6.6 V reference voltage of a buried Zener diode is amplified to a nominal 10 V using a precision auto-zero operational amplifier, the ADA4522-2. The ratio between the 6.6 V reference voltage and the nominal 10 V is almost exactly 1.50, allowing a ratio-matched resistor network to be used in the operational amplifier's feedback loop. The implementation is shown in Fig. 3, and a more detailed circuit diagram of the analogue section is shown in Fig. 4.

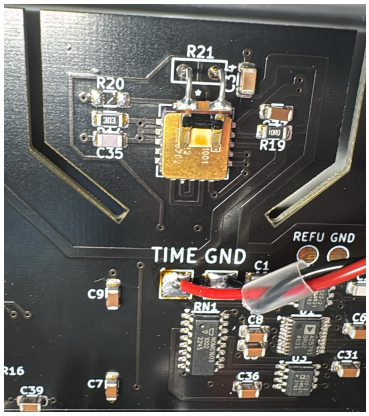


Fig. 3: Reference source of the midnight 23:59:59 (top), and digital-to-analogue converter with low-drift amplifiers (bottom)

The time in the microcontroller is controlled by an external interrupt at a frequency of 10 Hz, derived from an active hydrogen maser. If the clock needs to be moved and an extension lead from the maser would be impractical, the device is fitted with a thermostatically controlled, high-stability oscillator with frequency stability of ±10 ns/h over the range −20 to +80 °C and maximum one-year ageing of ±50 ns/year. However, the thermostatically controlled oscillator dissipates considerable power, significantly heating the inside of the clock and thereby affecting its accuracy.

3. DISTRIBUTION OF TIME TO ADJACENT 'SPECULATORIUMS' AND MULTIMETER ROOMS

Central and secondary clocks are commonly used in larger companies and laboratories. Time is transmitted to the secondary clocks mechanically by pulleys or electrically through wires.

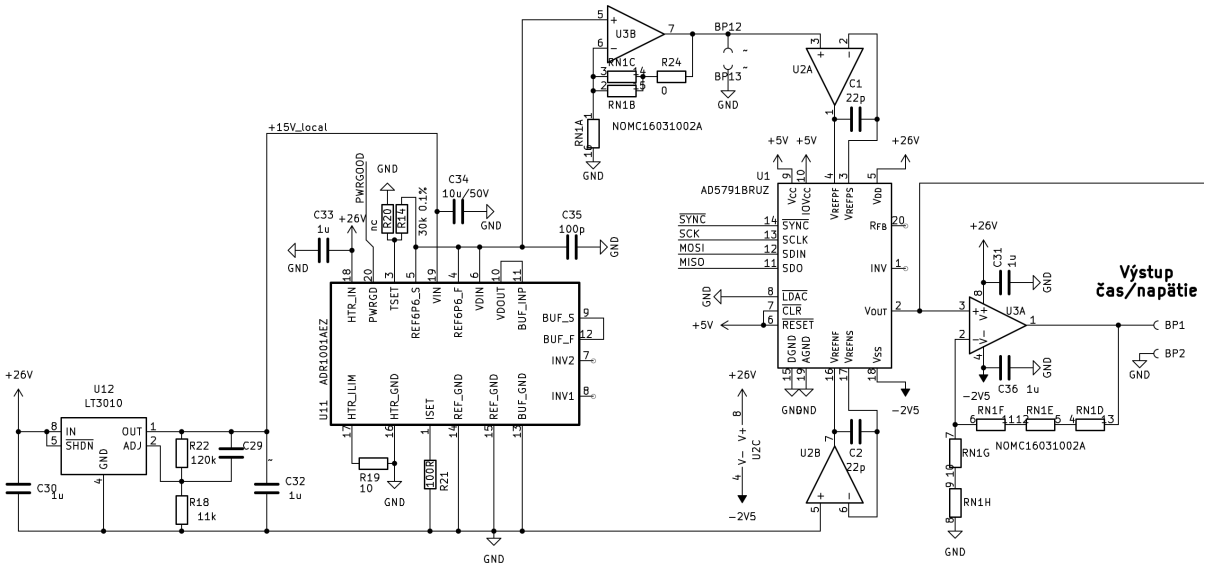


Fig. 1: Analogue part of the Metrologist's clock

The clock developed at DMI is no exception. Since distributing a precise voltage is not straightforward and is subject to errors and interference, we had to develop a robust method for distributing time to adjacent rooms. Current transmission does not suffer from these problems.

The Metrologist's Clock therefore incorporates a precision time-to-current converter. A current loop is routed to the other laboratories, and anyone who needs precise time can simply connect a reference resistor to the loop and measure the voltage drop across it with a multimeter, as shown in Fig. 5.

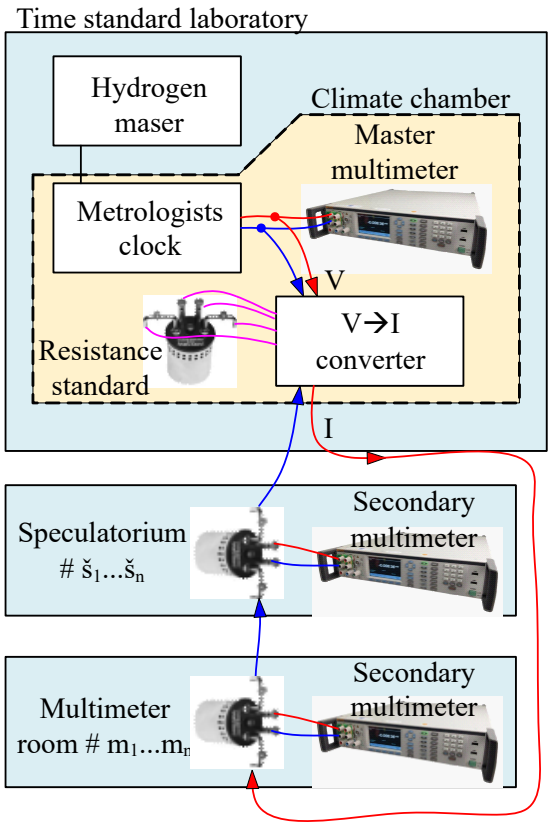


Fig. 5: Distribution of time to adjacent 'speculatories' and multimeter rooms.

4. METROLOGICAL CHARACTERIZATION

A. Temperature stability

Since the time reference comes from an external hydrogen maser, temperature does not affect the long-term drift. The

thermostatically controlled oscillator used when operating without the maser has a specified frequency stability of ±10 ns/h over its entire operating temperature range (−20 to +80 °C), so this influence can also be neglected. The analogue section—the reference source for midnight, the auto-zero amplifier, and the resistor networks—is the dominant contributor to the temperature stability of the Metrologist's Clock. Stability was tested in a climatic chamber over a temperature range of −10 to +50 °C.

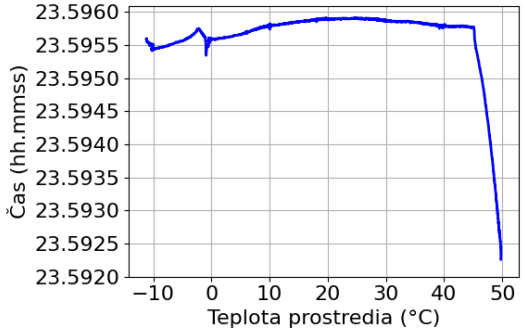
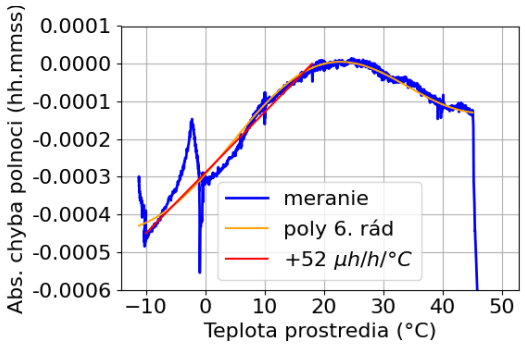


Fig. 6: Temperature stability of the reference source of midnight.



Obr. 2: Chyba polnoci ako funkcia teploty

Figure 6 shows the measured temperature stability of the reference source for midnight; Fig. 7 shows the maximum time error. The clock operates optimally over a temperature range of 20–30 °C. From −10 to 15 °C, the measured time error is approximately +50 mh/h/°C.

The temperature control of the buried Zener diode stops functioning at 45 °C, and the time error begins to increase sharply. This feature can be useful in laboratories located farther south, where precise time is of little importance at high ambient temperatures.



Fig. 8: The Metrologist's Clock in the climatic chamber. Live video https://youtu.be/3YUfwMxNAhw

B. Precision and Accuracy

Next, the precision and trueness of the output time were measured. A total of 345,565 samples were collected using a reference multimeter with an expired calibration; the integration time was 25 NPLC (500 ms).

Mean value:
$\overline{U_{OUT}} = 11{,}798706\ hr, minsec$,
Type A uncertainty:
$\sigma_A = 6{,}924206\ hr, minsec$ (k=1),
Type B uncertainty:
$\sigma_B = 0{,}000126\ hr, minsec$ (k=1)
Type C uncertainty:
$\sigma_C = 0{,}010200\ hr, minsek$ (k=1)

The measured data clearly show that, with 95% probability, the time is exactly:

11 hours, 79 minutes, and 87 seconds

±13 hours, 84 minutes, and 84 seconds

When calculating the Type A uncertainty, we noticed an interesting phenomenon that is unusual in metrological practice and requires further investigation. Normally, when uncertainty is calculated from a larger number of measurements, the resulting Type A uncertainty decreases. In the case of the Metrologist's Clock, however, it increases exponentially, as shown in Fig. 9.

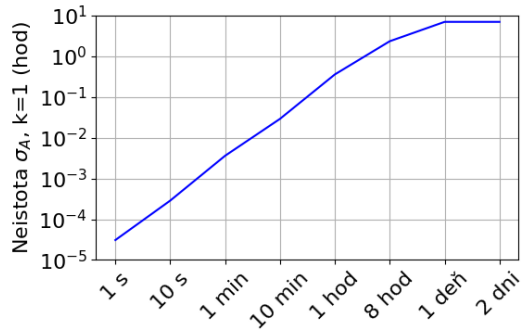


Fig. 9: Type A uncertainty as a function of measurement duration

5. ZÁVER

This article has presented the design and implementation of the Metrologist's Clock. Long-term metrological characterisation found that, with 95% probability, the time is exactly 11 hours, 79 minutes, and 87 seconds ± 13 hours, 84 minutes, and 84 seconds. With a small software modification, the clock can become a practical calibrator for voltage, current, and resistance [5].

For the best possible stability, it is recommended that the clock and the indicating multimeter be operated in a climatic chamber at +23 ± 0.1 °C and 50% RH.

LITERATURE

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This is a machine translated version of a scientific article, which was published in the *Annales Patroniensis* vol. III Nr. 1, 2025

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Translator's note (translated by ChatGPT): The source contains several deliberately humorous or nonstandard terms (including "mluno," "speculatories," and "multimeter rooms"); these have been retained or rendered literally where possible. Some equations and uncertainty values appear as non-text elements in the source and may not be fully represented in this editable text translation.