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RMS VOLTAGE MEASURING SYSTEM FOR PRECISE EVALUATION OF ELECTRIC QUANTITIES

This paper is about a system for the measurement of RMS voltage. One or more of these systems can be employed as components for a wide range of applications for the measurement of electrical quantities in the field of electrical metrology. The first implementation has demonstrated its functionality and the possibility to reach a stability of the AC voltage measurement in a wide frequency range with an accuracy within 10 parts in 10^6, limited only by the DC voltage accuracy of the DAC employed. A second implementation, now under investigation, aims at improving the accuracy of the system for high precision measurements.

Keywords: Thermal converters, RMS measurements, sampling technique, data acquisition

1. INTRODUCTION

Multijunction thermal converters [1] are the most precise devices available at the moment for the AC voltage traceability for frequencies up to 1 MHz. However, up to now, these converters have been used mainly in metrological laboratories, where they are employed to calibrate precise AC voltmeters or other AC measuring instruments. At Istituto Nazionale di Ricerca Metrologica (I.N.RI.M), Italy, like in other metrological laboratories, systems and methods have been developed for this purpose [2, 3].

As multijunction thermal converters are also available as components, the construction of specific measurement systems is considered in this work. The target is to build an electronic assembly, easily connectable to a computer for setting-up precision AC measurement systems, to be used both in a metrological laboratory and for usual precise measurements.

Applications for one or more of these subsystems will be the measurement of AC voltage or AC current, but also AC voltage and AC current ratio, power and impedance.

The behavior of thermal converters both in silicon and quartz in the low frequency range and upper acoustic range has been explored and evaluated in several works [4, 5, 6]. Measurements have been made by means of commercial instrumentation such as nanovolmeters, digital voltmeters, AC-DC calibrators and switches, or a system that uses a mix between commercial and building blocks as a digital synthesized source [7] or fast reverse switch [8].

2. THE SYSTEM

The construction of this system requires taking into account the specific characteristics of a thermal converter: its response in time, the drift of the electromotive force with a constant input voltage. In fact, the main valuable property of a multijunction thermal converter is not the stability of its input-output characteristics but the equal response to respectively the mean value of a positive and a negative DC voltage and an AC voltage having the same RMS value.

For this reason, to be used at its best level of accuracy, a thermal converter needs a good thermal circuit to assure a drift in temperature sufficiently regular during a period of some minutes.

Furthermore, in these conditions, for AC voltage or AC current measurements, some other requirements are also important:

– The electromotive force at the output of the device, which is at the level of 100 mV at the nominal voltage, must be detected with high accuracy and separated from noise and drift.
– The DC voltage supplied during the sequence must be both stable and known at the level desired for the AC measurements.
– In order to avoid a long settling time, the switching between AC and DC must be as quick as possible.

The basic scheme of the system is presented in Fig. 1.

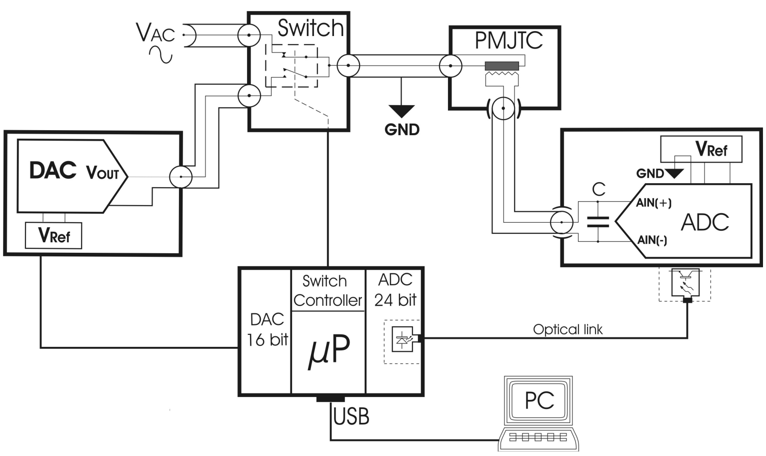

Fig. 1. Basic circuit of the system for the measurement of RMS voltage.

A planar multijuction thermal converter (PMJTC) can be supplied either by an external unknown AC voltage source or by an internal DAC through a two-position switch. An ADC is connected to the output of the thermal converter. The value of the electromotive force at the input of the ADC is read for fix time periods and the mean value is computed.

During the measurement sequence the AC voltage at the input of the system is connected to the thermal converter and the relevant electromotive force E_{AC} is measured. Then, from the parameters of the input-output characteristics of the thermal converter, previously stored in the computer, the sensitivity of the thermal converter $s = (\partial V/\partial E)_{VP}$ and the approximate DC voltage of the working point (VP) are evaluated.

In the following steps, beside to the AC voltage, voltages nearly equal to VP are applied by the DAC in both polarities and the corresponding electromotive forces are measured.

The AC voltage is then evaluated from:

$$V_{AC} = \overline{V}_{DC} + (\partial V/\partial E)_{VP}\left(\overline{E}_{AC} - \overline{E}_{DC}\right), \tag{1}$$

where $\bar{V}_{DC}$ is the mean absolute value of the DC voltage applied by the DAC, $\bar{E}_{AC}$, $\bar{E}_{DC}$ respectively the mean value of the electromotive force with the input connected to the AC voltage and the mean value of the electromotive force when the input is connected to the DC voltage.

3. FIRST IMPLEMENTATION

A first version of the system has been implemented for the experimental work and it is shown in Fig. 2. The main building blocks are separated and electrically isolated, but not in the coaxial form. The working band of the system is extended in range until the frequency of 100 kHz.

The following components have been selected:

- The multijunction thermal converter, which is put in a thermally protected enclosure, has an input resistance of 180 Ω and a nominal voltage of 1.5 V. The output resistance is about 10 kΩ and, at the nominal voltage, the electromotive force is about 108 mV. The input of the thermal converter is directly connected to the switch without a buffer and the output is connected to a 10 μF capacitor for preliminary filtering of the noise.
- The switch, for a fast transition between AC and DC, consists of two relays with mercury wetted contacts. The relays operate in this first version such that only the "high" connection is switched and the control of each of them operates separately with proper timing.

– The ADC for the measurement of the electromotive force is a sigma-delta component with 24 bit resolution, its input voltage range is selected between −160 mV and 160 mV, with about 20 readings per second.
– The DAC is a resistance ladder low noise device with 16 bit resolution. The maximum output current is 20 mA, so that it can supply directly the input resistance of the thermal converter at the nominal voltage.
– For both the DAC and the ADC, the voltage references are high accuracy and ultra-low drift ones, with a maximum specified variation with temperature of 3 ppm/°C and noise less than $100\mathrm{nV}/\sqrt{\mathrm{Hz}}$. They are set at 2.5 V by pin connection.

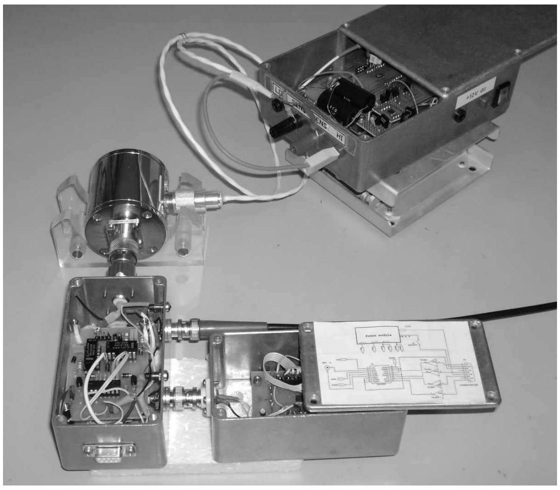

Fig. 2. First implementation of the system for precise measurements of RMS voltages suitable for preliminary tests.

Other electronic circuits have been included in the system for the control of the battery and for disconnecting the input when the RMS value exceeds 10% of the nominal voltage.

The ADC, the DAC and the switch are driven by a computer by means of an USB-SPI interface. The software that controls the system has been written in LabWindows and performs the following operations:
– Temporization of the sequence.
– Determination of the sensitivity from the stored parameters.
– Setting of the DAC voltage to proper values.
– Measurement of the electromotive force for every voltage supplied to the multijuction thermal converter.
– Storage of all data and evaluation of the ac voltage.
– Display of the results.

4. PRELIMINARY RESULTS

To evaluate the critical aspects of the operation, some preliminary results have been obtained with the multijunction thermal converter supplied by the internal DAC. The voltage at the input of the thermal converter was measured as a time function by a precision DC voltmeter and, at the same time, the electromotive force was acquired by the ADC.

The potential capability of the system can be summarized by the graph in Fig. 3. The graph V_{DC} line shows, after some time of acquisition, the variation in time of the voltage supplied by the DAC, while sE_{DC} is the corresponding variation of the electromotive force multiplied by the sensitivity $(\partial V/\partial E)_{VP}$.

The quasi-linear drift can be removed by a proper sequence of AC and DC measurements. From the graphs a degree of correlation between the two variations is clear which partially compensates for the instability of the voltage generated by the DAC. In fact, as shown in (1) the two terms plotted in the graph take part in the determination of the AC voltage with opposite sign.

So, if the DAC is calibrated at a sufficient level, measurements of AC voltage better than 10 parts in 10^6 can be made for frequency up to 100 kHz where the AC-DC transfer difference of the multijunction thermal converter is lower than this level.

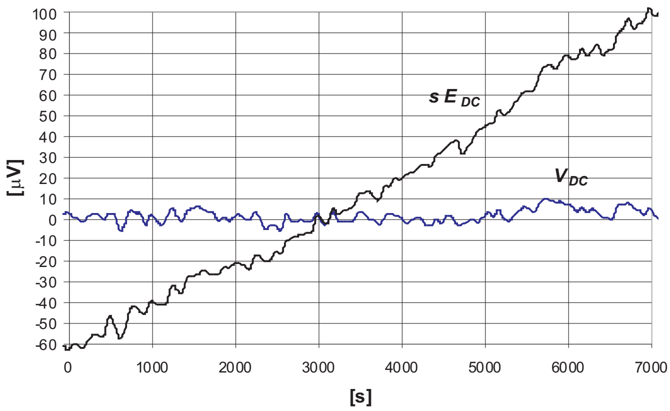

Fig. 3. Signals significant for the characterisation of the system. V_{DC} shows the stability of the DAC almost at the nominal value (1.4 V), sE_{DC} is the contribution due to the variation of the electromotive force for the same voltage.

5. NEW VERSION OF THE SYSTEM

A second version of the system has been designed and is now being implemented and its schematic circuit is shown in Fig. 4. The main differences with respect to the previous one are:

- The ADC for the measurement of the electromotive force is a sigma-delta component with 24 bit resolution and its input voltage range is selected is between 0 and 2.5 V. The data rate of the ADC is set by the speed pin. With data rate used of 10 samples per second the ADC has lowest noise and excellent rejection of both 50 Hz and 60 Hz line-cycle interference. To drive the ADC only two pins are needed and the offset error is removed by an auto-calibration procedure that can be initiated at any time. The gain of the internal programmable amplifier (PGA) of the ADC is set to one and it has a drift about 0.2 ppm/°C. In the operative conditions, the spread of repetitive measurements (1-σ) is about 420 nV RMS.
- Between the output of the thermal converter and the input of the ADC there is a low noise amplifier interposed. It consists of a couple of operational amplifiers configured as an instrumentation input/output driver with a total harmonic distortion (THD) better than –115 dB in the frequency range from 100 Hz to 30 kHz.
- The DAC has 20 bit resolution and a sigma-delta architecture. Compared to the previous version the maximum output current is 0.5 mA. The low noise buffer B (Fig. 4) guarantees the current required by the resistance input of the PMJTC sensor. For precision measurement the DAC architecture provides the self-calibration system in terms of offset calibration and gain calibration. Both codes are stored in a separate register called offset calibration register and full-scale calibration register.
- The system is isolated from its digital control unit by means of optical links.

The ADC, the DAC and the switch are connected to a computer by means of an USB-SPI interface. The software that controls the system is charged on the flash memory of the board. It has been written in LabWindows and a suitable new library of commands in this language has been constructed.

In the software program the following upgrades have been introduced:

- The full code was developed inside the micro-controller (quasi real time system) to drive the ADC and DAC.
- The final code is sent to the PC according to the new full-speed specification of USB 2.0.
- The PC only needs a minimum code to work and the transfer speed is limited only by the operating system installed.

In order to eliminate a ground loop between input sources to be compared and between sources and the measuring system , the electrical isolation resistance has been incremented using Teflon covering for most connectors with respect to the chassis ground. At the same time the ground of the computer is not connected with the instrument's chassis using only the two differential wires that the USB connection offers, eliminating the ground loop between the PC and the system. At this level the influence of this ground loop is not quite clear, but this does not exclude the possibility to develop an optical system to eliminate completely each interaction between the PC and the system.

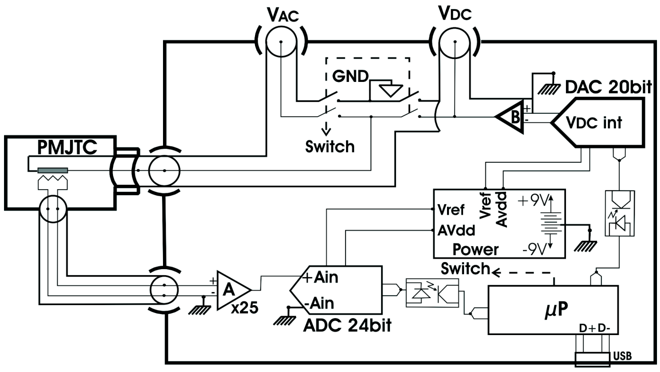

Fig. 4. Schematic circuit of the new system.

The two boards of the DAC and the ADC, specifically built for the system, are shown in Fig. 5.

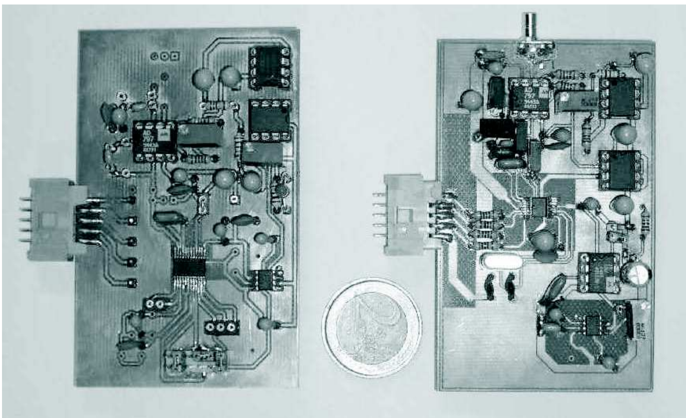

Fig. 5. ADC (left side) and DAC boards specifically built for the system.

This new version has not been tested as an entire system yet. But, from the preliminary tests on the subsystems, the following features are expected:

– The increased DAC accuracy and resolution results in a most precise reference DC voltage, at a level of less than 3 parts in 10^6.
– The noise introduced in the measurement of electromotive force of the thermal converter by the amplifier and the ADC is lower than 100 nV.

6. CONCLUSIONS

The functionality test and the experimental results on the first experimental system have shown the feasibility of a system for the precise measurement of a RMS AC voltage in a wide frequency range by means of a simple electronic circuit which can be used for many applications in the field of the electrical metrology.

The first experimental system was not optimized. In the new version with a more precise DC voltage reference, a different DAC with higher resolution and a precise low noise amplifier at the output of the multijunction thermal converter have been introduced. In this way, we expect that the system will operate at a level of accuracy adequate for high precision measurement instruments.

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