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A LINK BETWEEN TRADITIONAL AND MODERN TECHNIQUES IN THE MEASUREMENT OF AC VOLTAGE

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Abstract – The precise measurement of ac voltage is traditionally performed by thermal converters. However, these devices are impractical outside the laboratories and the development of DACs and ADCs seems to provide a possibility for new high precision techniques. This paper investigates this problem and, by means of some experimental comparative tests, analyses these new possibilities.

Keywords: AC generators, Thermal converters, Transfer standards, Digital measurements

1. INTRODUCTION

The measurement of ac voltage is of fundamental importance in modern applications. There are a lot of fields where these measurements are currently applied: industry, biomedical, avionics, power plants, generation and distribution of electrical energy, communications, electronics and automatic controls. In all these activities the possibility to check and measure the ac quantities with an adequate accuracy is required and the instruments for these purposes have to be calibrated, sometimes with high accuracy.

The evolution of the electronics components and the use of high resolution analog to digital converters (ADCs) or digital to analog converters (DACs) have opened the possibility for the construction of modern precise instruments (over 6 digits), operating in a frequency range from 10 Hz to 100 kHz and with a level of accuracy of 1×10^{-5}. Furthermore, some high level instruments which operate in the range from 1 mV to 1000 V up to 1 MHz need good metrological characteristics, such as stability and accuracy. They have also to be adjusted and periodically calibrated to maintain their traceability.

The adjustment and calibration procedures require standards traceable to SI units and referred by an unbroken chain to the standards of a Primary Metrological Laboratory.

The precise measurement of ac voltage is often obtained by planar multijunction thermal converter (PMJTC). This device assembles inside two main parts: a heater constructed by a thin film resistive element and a temperature sensor built by a series of thermocouples junctions.

The PMJTC is based, in principle, on equivalence of the power dissipated. The relative difference between two voltages: the ac voltage and the corresponding dc voltage that produces the same electromotive force at the PMJTCs output is known as the transfer difference δ.

$$\delta = \left. \frac{U_{ac} - U_{dc}}{U_{dc}} \right|_{E_{ac}=E_{dc}} \tag{1}$$

The evaluation of δ allows us to use the thermal converter as a transfer standard for the estimation of the rms value of an ac voltage by means a PMJTC sensor as described in [1]. At INRIM the transfer standard for ac voltage between 1 V and 3 V is built by a group of 3D multijunction thermal converters. For higher voltages, PMJTC or single junction thermal converters are associated to coaxial range resistors to produce a voltage divider with ratio almost independent of the frequency [2]. Resistive and inductive dividers are employed for the measurement of low voltages [3], [4].

Alternative precise measuring systems for the evaluation of ac electric quantities employ principally thermal conversion or sampling techniques based on commercial components and there are indications which demonstrate that digital to analog converters (DAC) based on quantum effects will develop in future.

In this paper same measurements have been performed to link these methods and to evaluate the possible implication of the new components in systems at primary level.

2. PRECISE GENERATION AND MEASUREMENT OF AC VOLTAGE BY MEANS OF DAC AND ADC

The precise measurement of the ac voltage, especially for low frequency (e.g. up to 100 Hz) can be made by means of analog to digital converters (ADCs). At the moment, there are high resolution converters (16 bits and beyond) that can perform precision sampling of the measurement signals at higher frequencies. After the acquisition, suitable methods of signal processing can reconstruct the signals, evaluating the parameters of interest like the rms value and all the possible information as function of time and frequency (i.e. the harmonic contents).

A first precision measurement system, based on sampling has been set up at INRIM for the voltage measurement at frequencies lower than 20 Hz [5], where the ac-dc transfer difference in thermal converters is not negligible as an effect of the instability of the temperature in the heater. The same method has been extended to a two channels and has been employed for the primary measurement system of electrical power [6].

The wide diffusion of ADCs, some characteristics of which are shown in Fig. 1, allows extending of frequency band and amplitude resolution in modern measurement systems.

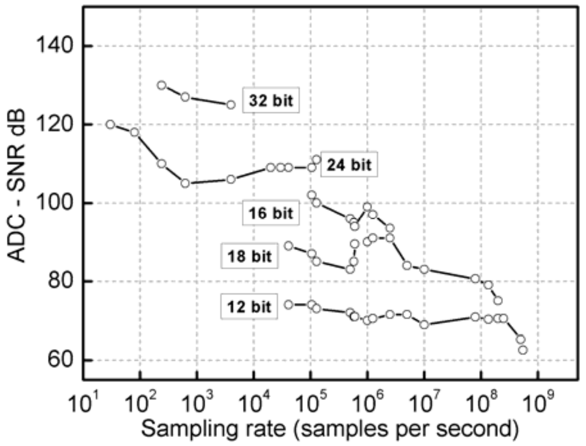

Fig 1. Signal to noise ratio of some commercial ADCs as function of sample rate and resolution.

By means of ADCs it is possible also to make measurements for frequencies higher than those previously stated, even if the uncertainty are, at the moment, worse than that of the thermal converters. However, in the next future, they will be probably better with the possibility of implementing systems with a frequency band up to several kilohertz and measurement uncertainties better than some parts in 10^6.

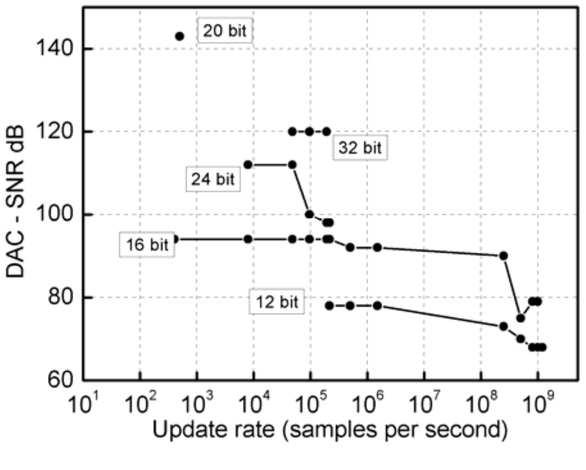

Fig 2: Signal to noise ration of some DACs as function of update rate and resolution.

By means of DACs instead it is possible to generate a signal with given characteristics, which can be employed to calibrate the measuring instruments. This approach has been used in the past [7] and also applied to commercial instruments.

The innovative characteristics of the recent DACs make them suitable to improve the signal generated. In Fig. 2 the signal to noise ratios of some DACs components of recent construction are reported. Also for these components it is necessary to evaluate the correct tradeoff between the frequency band, the resolution and the total harmonic distortion.

Further techniques for generating step functions that approximate better the desiderated signals are those employing arrays of Josephson junctions programmed in suitable sequences. In this way, the amplitude of the steps is traceable to a frequency with a high accuracy (parts in 10^9). With a proper timing it is possible to reduce the errors introduced by the jitter and of the filter at the output of the generator made by the Josephson array and obtain high accuracy of the signal.

Then, in principle, by combining a Josephson array generator with a suitable comparator, a voltmeter completely traceable to fundamentals constants can be obtained.

3. COMPARISON OF TWO METHODS

A method based on the sampling approach, to synthesize ac and dc voltages in a bandwidth of interest, by means of the direct digital synthesis has been set up.

The novelty consists in designing a frame with a traditional ac - dc transfer one cycle input and generates it continuously. The ac and dc levels of the composite waveform are compared by a PMJTC chip, which has the lowest ac - dc difference.

The digital generator uses a similar principle as described in [8]; instead, at present, a single DAC channel is used to synthesize both ac and dc voltages. The reference voltage of the DAC can be provided be means of an external precision dc source.

Normally to implement the ac - dc transfer procedure a switch unit must be used. A changeover in the switch unit has been introduced. It consists in the implementation of a virtual programmable switch unit, instead of an external electromechanical switch (see section 4.2). This means an improvement in terms of speed of the switching time between the various waveforms, flexibility and the total elimination of several problems regarding the electromechanical switch as its construction and the contact resistance which is not negligible.

Two series of tests have been performed in order to understand the performance of this system and the limits compared to the traditional methods adopted by several National Metrology Institutes (NMI).

4. THE MEASURING SYSTEM

The system is composed by three main blocks. Fig. 3 shows the arrangement of the measuring system.

4.1. Digital synthesizer device for ac - dc voltages

The digital generator is based on a PCI board with 8 DAC outputs but for this purpose a single DAC channel is sufficient. The DAC - board is inserted within a personal computer (PC) and an external extension box, with several BNC connectors, is connected with the board by a special cable. In this way the output channels of the DAC - board and auxiliary input signals, as an external frequency reference and an external dc voltage reference, are easily accessible.

The amplitude of the analog output depends directly from the value of the dc voltage reference (see section 4.3). With this system it is possible to generate by programming, either periodic or non periodic synthesized waveforms.

Some main characteristics of the DAC - board are; resolution of 16 bits, maximum update frequency $f_U = 1{\times}10^6$ Hz and maximum output current 20 mA. Theorically the lowest dc quantization in terms of voltage reference V_{Ref} can be calculated as $\Delta V = 2 \cdot V_{\mathrm{Ref}} / 2^{16}$.

When periodic waveforms are generated with a fundamental analog frequency f_a the maximum number of points in each period can be calculated as $N = f_U / f_a$.

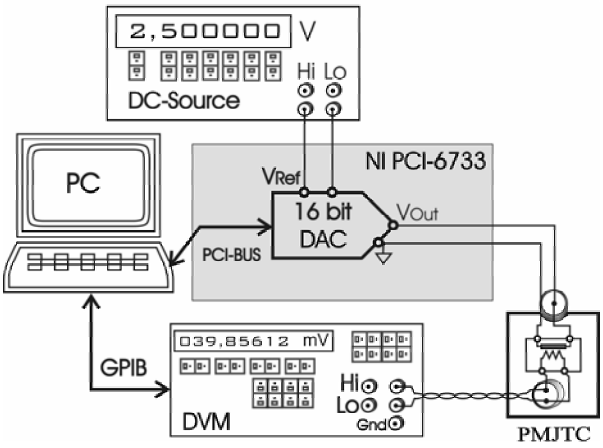

Fig. 3. Basic circuit of the comparison system.

4.2. Virtual fast ac - dc switch

Fast reverse dc (FRDC) method [9], or fast synchronous switching during the ac-dc transfer measurements [10] requires the construction of a fast coaxial switch. However it is possible to construct a virtual switch, without using electromechanical or fast semiconductor components, by means of a programming strategy where the FRDC method is applicable also from ac to dc commutation and viceversa.

The switch is designed keeping in mind the classic procedure used during the ac - d*c* transfer standard. The action of a switch, in our case, is to shift a signal an ac or dc voltage, in the input of the PMJTC element. This virtual switch consists in loading into a buffer the synthesized waveform respecting the sequence ac — $dc^{(+)}$ — ac — $dc^{(-)}$. This sequence is repeatedly performed by means of the circular buffer approach.

The input parameters to be inserted are, the frequency of the sinewave and the amplitude respecting the maximum input limit of the PMJTC element. The output of the DAC changes level according to the digital values preloaded in the frame buffer, which are stored in the memory. The time that two memory allocations are put off is inversely proportional to the update rate $\Delta t = 1/f_U = 1\times 10^{-6}$ s. Fig. 4 shows a frame of the waveform buffer which contains the standard cycle of an ac - dc transfer procedure.

4.3. Reference dc source

The performance of DAC - board, in terms of amplitude resolution, can be fully exploited when the maximum analog voltage needed in the output equals the reference voltage. So, if the level of ac and dc voltages to be compared is lower than 10 V, instead of the internal voltage reference, an external voltage reference (a dc calibrator or a solid state source or a Josephson array) can be used.

A precision dc calibrator has been used, as shown in Fig. 3, which has performances in terms of long term stability and voltage noise better than the internal voltage reference of the DAC - board. Internal circuitry of the DAC - board has an input resistance of 1 MΩ and this doesn't present complication, when an external source having low output impedance is used.

The output of the dc calibrator, in this experiment, is programmed in a range between 1.5 V and 5.0 V. As mentioned previously the DAC - board exploits full resolution when the relation $V_{\mathrm{Ref}} \geq V_{\mathrm{ac}}^{\mathrm{p}} = \sqrt{2} \cdot V_{\mathrm{ac}}^{\mathrm{rms}}$ is satisfied, where $V_{\mathrm{ac}}^{\mathrm{p}}$ is the maximum amplitude of the sinewave.

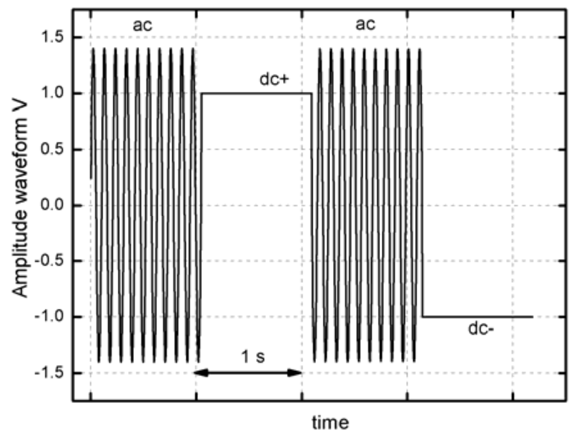

Fig. 4. A frame of the buffer containing the synthesized waveform and the switch between ac — dc signals.

4.4. Electromotive force measuring system

The electromotive force, E_{fm}, of the PMJTC element is measured by means of a DVM instrument. However, other methods based on the approach of sampling ADCs converters can be used to evaluate the E_{fm}.

A user friendly interface in labwindows/CVI has been developed in order to set the parameters of the digital synthesizer (amplitude, frequency and phase) and acquiring system, DVM, for the E_{fm}.

There are two methods of measurements that can be employed; fixed frequency and amplitude, which gives information regarding the repeatability and stability; automatic sweep, which employs the ac - dc transfer procedure at fixed voltage but variable frequency from 20 Hz to 100 kHz.

5. PRELIMINARY RESULTS

First results based at a fixed frequency and voltage level of 1V, Fig. 5 lower part, shows that stability of the transfer difference within some hours is better than 2 µV/V at 2 kHz. At upper part of Fig. 5 is reported the mean value in terms of equivalent input dc voltage calculated as,

$$\Delta_{\mathrm{dc}} = \left(\frac{E_{\mathrm{fm}}^{+\mathrm{dc}}(i) + E_{\mathrm{fm}}^{-\mathrm{dc}}(i)}{2} - \frac{E_{\mathrm{fm}}^{+\mathrm{dc}}(i-1) + E_{\mathrm{fm}}^{-\mathrm{dc}}(i-1)}{2} \right) \cdot \frac{1}{S} \qquad (2)$$

where $S = \partial E_{\mathrm{fm}} / \partial V_{\mathrm{in}}$ is the sensibility of the PMJTC experimentally determined and V_{in} is the input voltage.

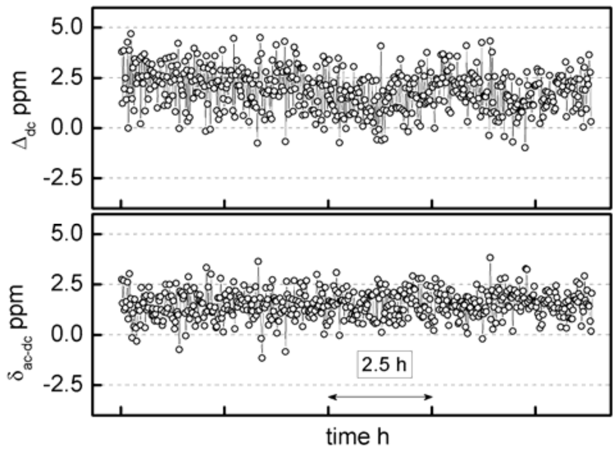

Fig. 5. Long term stability and drift within some hours at 1V level at fixed frequency with 3 V external dc voltage reference.

The ac-dc transfer difference in this particular experiment is less than 15 parts in 10^6 up to about 5 kHz as shown in Fig.6. Apparently, in the range up to 10 kHz there is a fix component and a component proportional to the frequency.

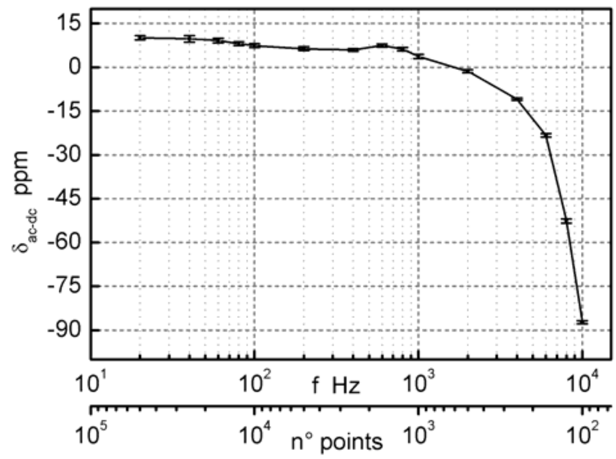

Fig. 6. Comparison of ac and dc voltages at 1 V level generated by the 16 bit DAC board at different frequencies and fixed external voltage reference V_{Ref} = 2.5 V.

From experimental data the linearity of the transfer difference δ versus frequency can be evidenced up till 5 kHz. Further investigations regarding the influence of the harmonics or other possible causes on the linearity of the transfer difference are under analysis and possible future results will be given at the conference.

6. CONCLUSIONS

DACs and ADCs have been experimented as components for high precision reference of ac - dc transfer difference to be employed in new high precision techniques for ac voltage measurements.

A preliminary experimental test on a DAC has shown a good repeatability of the result and the possibility to build model of the ac - dc transfer difference as a function of the frequency. If confermed by further experiments the application of this model will allow us to improve widely the accuracy of the ac voltage measurements.

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