INCREASING THE MEASUREMENT ACCURACY AT LOW FREQUENCIES BY SUCCESSIVE EXTRACTION OF THE ABSOLUTE MEAN VALUE

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Abstract - *A method for the precision measurement of the RMS value of a low frequency voltage signal is described in this paper. The method consists in one or more stages that perform basically the same function, even if they can differ for the level of accuracy required. Each stage performs: the determination of the absolute value as function of time and the extraction of its mean value. Actual realization by means of an electronic circuit shows that accuracy at the level of 1 part in 10^4 can be easily reached.*

Keywords - AC measurement, voltmeters, analogic signal processing.

1. INTRODUCTION

The precision measurement of the RMS value of an AC voltage can be performed by different methods, such as for example by sampling the signal and reconstructing it [1], by a thermal transfer standard [2] or by squaring the signal by analogic processing. All these methods have been applied in commercial instruments. However, when the level of accuracy required is better than 1 part in 10^4, their implementation can be expensive.

In the frequency range from 10 to 100 Hz, which also comprises the power frequency, the application of a relevant method [3], based on the analogic processing of the signal, can be a convenient alternative choice.

This method consists of successive extractions of the absolute mean values, which can be applied both for increasing the accuracy of ordinary RMS voltmeters and, with a multiple stage system, to obtain directly the RMS value.

2. THE METHOD

The method can be implemented by means of some stages operating in principle in the identical way. These successive stages can be put in cascade adapting the input level by precision amplifiers.

Each stage is ideally built by the elements shown in Fig. 1.The analog processing that are performed inside each stage produces the following signal:

- the absolute value of the input signal is obtained by mean of a proper circuit;
- the mean value of the absolute signal is achieved by means of a low pass filter and is sent to one of the outputs;
- the mean value is subtracted from the absolute value and the absolute value without the DC component is sent to the other ouput.

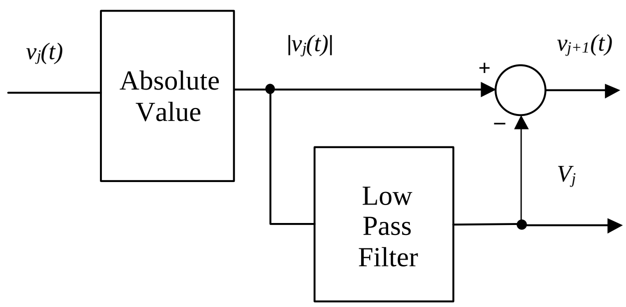

Fig. 1 Basic circuit of one stage

The absolute value without the DC component can be sent to the successive stage or read by a suitable RMS voltmeter, while the mean value is read by means of a DC voltmeter.

For the generic stage *j*, $v_j(t)$ is a voltage signal as a function of time at the input of the stage. Its RMS value is:

$$V_{RMS,j}^2 = \frac{1}{T}\int_0^t v_j(t)^2\ dt = \frac{1}{T}\int_0^t \left|v_j(t)\right|^2\ dt \qquad (1)$$

The input signal is processed by the circuit for the determination of the absolute value as a time function and of the mean value $V_{j,}$ which is extracted and measured.

Then the new signal $v_{j+1}(t)$ at the output of the stage is:

$$v_{j+1}(t) = \left|v_j(t)\right| - V_j \qquad (2)$$

As the DC component has been extracted, the mean value of $v_{j+1}(t)$ is null. So, the following recursive relation for the RMS value can be derived:

$$V_{RMS,j}^2 = \frac{1}{T}\int_0^T v_{j+1}(t)^2 \ dt + \frac{1}{T}\int_0^T V_j^{\ 2} \ dt = V_{RMS,j+1}^2 + V_j^2 \quad (3)$$

The RMS value at the input of the whole chain can be derived by combining these relations for all stages of the system and it is given by:

$$V_{RMS} = \sqrt{V_1^{\ 2} + V_2^2 + ... + V_n^{\ 2} + V_{RMS,n}^{\ 2}} \quad (4)$$

where: n is the number of the stages used in the system, V_j is the mean value at the output of the j-th stage and $V_{RMS,n}$ is the RMS value at the output of the n-th stage.

3. APPLICATION OF THE METHOD TO A PERIODIC SIGNAL

As an example to clarify the application of the method, a sinusoidal signal of 1 V RMS value is applies to the input of a six stage system. The absolute value signals without the DC component of the first four stages are shown in Fig. 2, while the mean and RMS values of the absolute signals are instead given in table 1. The same table reports also the error in percent of the resulting value computed by combining with relation 4 the DC outputs up to the j-stage, without taking into account the RMS value at the last output.

As shown in Fig. 2 the outputs of consecutive stages have an increasing frequency band that have to be taken into account while designing a real system. These output signals can be seen as a series of multiplications between each input signal and a square waveform with a suitable duty cycle; so the resulting spectrum can be obtained by the convolution of their respective spectra.

From the data computed in the same table, it can be shown that, for a nearly sinusoidal signals, two stages are sufficient to improve of one order of magnitude the accuracy of an RMS voltmeter.

4. AN IMPLEMENTATION OF THE METHOD BY AN ELECTRONIC CIRCUIT

The method proposed can be implemented by means of electronic circuits in several ways, depending on the level of accuracy required to the stage and the frequency band of the signal to be measured. Some possible implementations have been designed by employing standard electronic circuits [4].

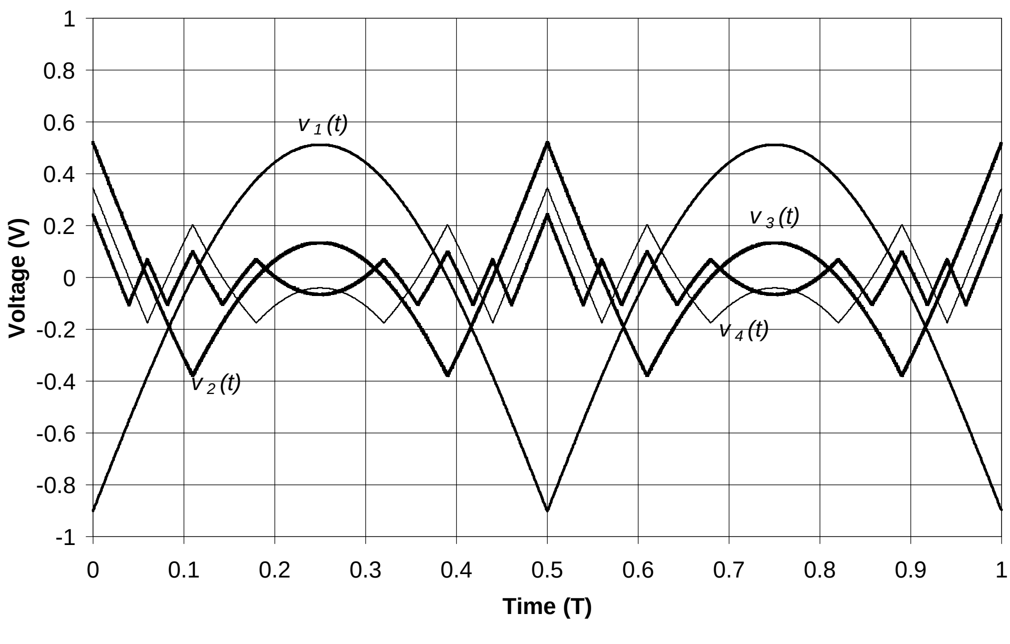

Fig. 2 Output of the first four stages, in a multistage system, when a sinusoidal voltage signal of 1 V RMS is applied to the input (the time is in periods of the input signals)

Table 1: Example of the application of the method to a sinusoidal signal

Stage	Mean value	RMS value	Error [%]
1-st	0.900316	0.43523	9.96
2-nd	0.379058	0.21388	2.31
3-rd	0.173980	0.12440	0.777
4-th	0.104130	0.06807	0.232
5-th	0.053821	0.04168	0.086
6-th	0.029366	0.02957	0.044

One of these circuits, suitable for medium frequency and medium accuracy, is here described. In this circuit only three integrated circuits have been used: a special circuit for the construction of the absolute value, one for the filter and an instrumentation amplifier to subtract the mean value from the absolute value.

The first part, represented in Fig. 3 is a circuit for the construction of the absolute value. It consists of a single integrate circuit that contains three differential amplifiers, two analogic switches, and a comparator. The circuit employed, on the basis of the sign of the input signal, can assume two different configurations: an amplifier with gain 1 and an amplifier with gain -1. The feedback increases the transition speed.

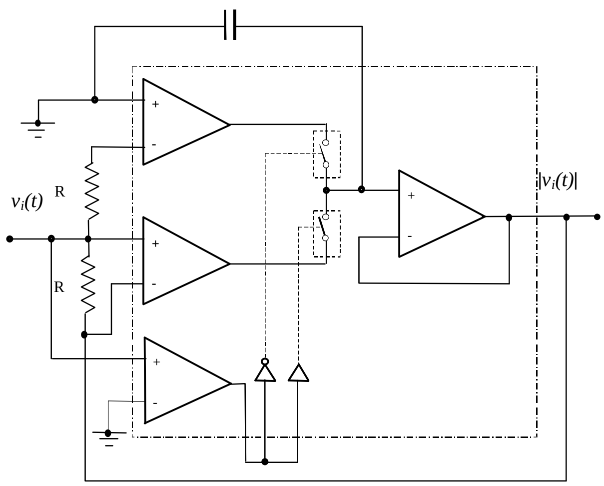

Fig. 3 Detailed scheme of a circuit for the determination of the absolute value used in the prototype

The second part of the circuit, represented in Fig. 4, contains a low pass filter and an integrator connected in feedback with an instrumentation amplifier. This circuit cancels the DC component at the output of the instrumentation amplifier by adding a suitable value to one of its input. This value, established by the feedbak circuit, is exactly the mean value of the signal at the input if the instrumentation amplifier has a unity gain. In this case the output of the instrumentation is inverted with respect to the basic circuit in Fig. 1, which however can be implemented exactly by means of an additional inverting amplifier. However the circuit in Fig. 4 does not change the result given in relation (4).

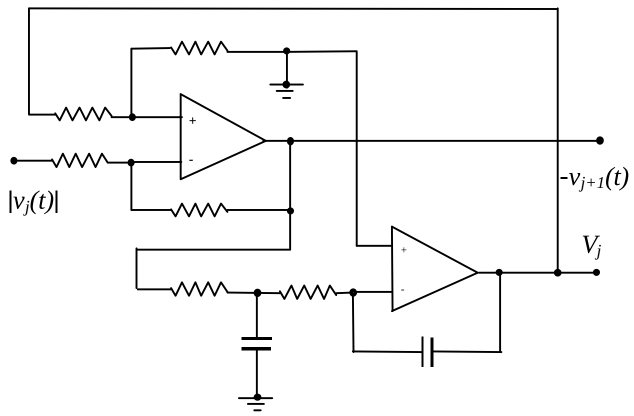

Fig. 4 Circuit used in the prototype for the determination of the mean value and its subtraction to the absolute value.

Tests on the outputs of this circuit at 53 Hz by means of precision instruments have shown that an accuracy for both the mean and RMS values better than 1 part in 10^3 can be obtained even without any adjustment of the offset. The accuracy can reach the level of 1 part in 10^4 by adjusting with proper trimmers the offsets.

At present, an implementation of a circuit for the first stages with refined electronic components and for an improved accuracy is under development.

5. CONCLUSION

In conclusion, with the application of this method, a significant increase in the accuracy of the measurement of the RMS value of an AC voltage is possible by using simple and low cost electronic circuits. Furthermore, the same principle can be also employed in the construction of a new type of instrument.

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