Precision Low frequency AC Voltage Source and Its Calibration Method

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Abstract Because of special performance of Precision low frequency AC voltage source and measurement devices, the evaluation and calibration of them are limited in deficient (in general, the DMM AC voltage measurement can not be available when input AC frequency is lower than 10Hz). The paper presents a method for designing low frequency AC voltage source and a corresponding method for calibrating to low frequency AC voltage source. Based on the low frequency AC voltage source, a new sampling computing method was presented .By using a precision sampler and quantizer, the low frequency AC voltage calibration system was setup. By employing the DDS technique, the accuracy and stability of low frequency AC voltage source were enhanced greatly.

Keywords:low frequency,voltage,measurement,calibration

I Instruction

Precision low frequency AC voltage sources have many applications in industry, aerospace environment model analysis and engineering tests, such as mechanical vibration testing. Because of their special characteristics of test, the measurement and calibration of them are limited in deficient (in general, the DMM AC voltage measurement can not be available when input AC frequency is lower than 10Hz). The paper presents a method for designing low frequency AC voltage source and a corresponding method for calibrating to low frequency AC voltage source. Based on the low frequency AC voltage source, a new sampling computing method and a precision sampler and quantizer, the low frequency AC voltage calibration system was setup. By employing the DDS technique, the accuracy and stability of the low frequency AC voltage source were enhanced greatly. And relying on a high accuracy sampling computing method, the precision calibration of these sources was completed. In the paper, based on frequency domain, the DDS theory and its performance was studied. Depending on the results of analysis, the designing method was presented. For the purpose of evaluating the low frequency AC voltage source, the sampling computing method was used to the evaluating process. A precision sampling DMM was used as sampler and quantizer, and the samples of DDS source are transported into computer with GPIB instrument control bus.

II Sampling and Computing Method

The process of sampling and computing is divided two independent steps. The first is sampling and digitization. The second step is computing. The input signal U(t) is sampled and digitized and the discrete data

U(i)(i = 0,1,2,……N-1)

are acquired and stored in computer trough the special instrument bus under the control of computing program. The RMS (root mean square) value, Urms of U(t) is gained by calculating as following:

$$U_{rms} = \sqrt{\frac{1}{N}\sum_{1}^{N} U_i^{\ 2}} \qquad (1)$$

during sampling and digitization, measurement uncertainty is mainly from the limitation of ADC resolution. When the ADC signal range is defined as (-R,R), and ADC's resolution bit is m, the analog level of one LSB is

$$q = 2^{1-m} \times R \qquad (2)$$

The possibility density function, following the uniformity distribution, is a constant value at the range (-q/2, q/2). The variance of digitization uncertainty is:

$$D(e) = q^2/12 \qquad (3)$$

The error caused by dither of sampling time base is another source of measurement. In general, the error △t submits to normal distribution. If the error scope is defined between -3δ and +3δ,the accuracy of the measurement to sine signal is expressed by the equatation (4)

$$\delta_{rms} \approx \pm \frac{3}{\sqrt{2N}} \sigma_t \omega_s \qquad (4)$$

from (4),the standard deviation of sine RMS value, is positive proportion to standard deviation of △t (normal distribution); and it will be direct proportion to increasing of sine signal frequency.

In general, front end of data acquire device consists of preamplifier, tracer and holder, ADC. Anyone of them has error that mainly caused by offset deviation and gain difference. If not reducing the error caused by offset and gain, the data output by data acquisition device will carry static error. To remove the error from offset and gain deviation, some special circuit are designed, as showing in figure (1)

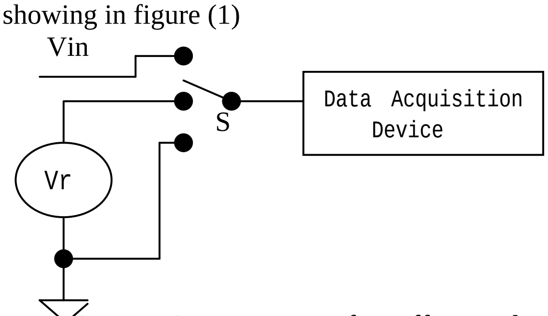

FIG. 1 Compensating for offset and gain error

Before data acquiring, the data acquisition device should complete following operations to compensating offset and gain error.

(1)switching S to ground, and recording U1, the output data of data acquisition device(DAQ);

(2)switching S to reference voltage Vr and recording the output data U2 assuming K to express the gain of DAQ, and from the operations results above, some equations are gotten.

$$U_1 = U_{os}$$
$$U_2 = KU_r + U_{os}$$

then, $$K = \frac{U_2 - U_1}{U_r}$$

and output of DAQ can be given:

$$U_o = KU_{in} + U_{os}$$

and input value is:

$$U_{in} = \frac{U_o - U_1}{U_2 - U_1} \times U_r$$

Because of influences of environment parameters (such as temperature), the offset and gain of DAQ are changed with time, the correction of DAQ offset and gain will spend more time during the measurement process.

III Measurement System Setup

To ensure the precision of system sampling and digitization, high accuracy DMM, HP3458A was chosen as the sampler and digitizer. The meter is a DMM, and it may measure the frequency of input signal within some extension. The measurement process is implemented under the control of main controller. Following the front analogy circuit for base resistance, current and voltage signal conditioning, a ADC, sampler and digitizer converts the input analog signal with a high accuracy and high resolution. Main controller is made of MCU, programming ROM, data RAM and calibration RAM, and controls whole measuring process. Input range of ADC is controlled by amplifier and attenuation, if ADC dynamic range is (-10V,10V), the pre-amplifier and attenuation will configured gain coefficient with 100,10,1,0.1,0.01 respectively to 0.1V, 1V,10V,100V,1000V range of DMM. Before measuring, DMM completed the calibration by itself and stored the calibration parameters into its memory. HP3458A has three kinds independent signal digitizing mode shown as table (1).

Table (1)

Digitizing mode	Input width	Sampling speed	Accuracy
Normal DCV	DC-150kHz	100k/s	0.00005% -0.01%
Directly sampling	DC-12MHz	50k/s	0.02%
Equivalent	DC-12MHz	100M/s	0.02%

To optimize sampling digitizing accuracy and improve their efficiency, DCV sampling digital mode was selected, and the reasonable system parameters were set. The choice of integral time (integrate ADC in HP3458A) was related to power frequency cycle, for consideration of accuracy and resolution. In addition to the advanced sampling mode, the numbered relation between the aperture time of sampling and ADC's output performance was deliberated, some configure command and specifications shows as table (2). HP3458A supports deferent analog channel in front of ADC. It is showed as Fig. (2)

Table (2)

Instruction Format	Integral Time	
	50Hz	60Hz
NPLC0	500ns	500ns
NPLC0.5	10ms	8.333ms
NPLC1	20ms	16.6667ms
NPLC10	200ms	166.667ms
NPLC11	200ms	166.667ms

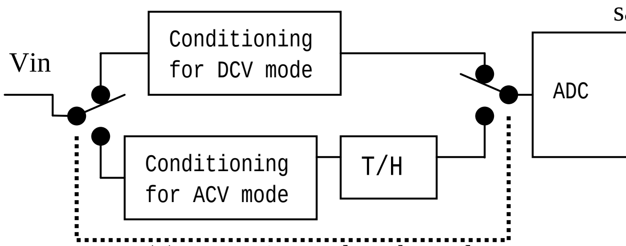

Fig. (2) HP3458A analog channels

The instruction "PRESTDIG" can be used for setting the mode DCV or ACV. And the default configure parameter was built as follow:

(1) FSR: 10V; samples number: 256; sampling frequency: 50kSPS.
(2) Trigger parameter: AC coupling; trigger level:0V, positive slope.

Under DCV mode, 18bit(6kSPS) to 16bit (100kSPS) can be gotten respectively.

LabWindows/CVI is a development environment for programmers. By using the tool, which includes many function library facing programmer, the virtual interface operation board was designed and programmed. By using the powerful math library of LabWindows/CVI, the RMS value of signal measured was calculated. In order to gain exact N, it is essential to measure accurately signal cycle. The ordinary method of measuring frequency is hardware method. However, for low frequency signal, because of much too long time of its cycle (16.67 minutes for one cycle of 0.001Hz signal), it is difficult to lock exactly the frequency of measured signal. The method of hardware zero-cross requires much better stability of comparator. In the measurement project, frequency measured by software was taken. Configured trigger sampling mode by main computer, ADC gathers data and transfers to main computer until the sample number reached N. In the date group, a zero-cross was detected by software sub-program and the cycle of the measured signal can be gotten.

IV Error Analysis

The error of system sampling and computing for RMS value includes the error of sampling digitizer and computing. The error of sampling digitizer is decided by HP3458A and corresponding sampling mode. The computing error roots in the finite word length respond of the computer and the computing error of sampling signal cycle. From the analysis of sampling process, cycle error is from ± 1 sampling timing interval. The virtual value error is,

$$\Delta V_{\gamma ms} = \sqrt{\frac{1}{N-1}\sum_{i=0}^{N-2} V_i^2} - \sqrt{\frac{1}{N}\sum_{i=0}^{N-1} V_i^2}$$

$$\gamma_{rms} = \frac{\Delta V_{\gamma ms}}{V_{rms}} = \frac{\sqrt{\frac{1}{N-1}\sum_{i=0}^{N-2} V_i^2} - \sqrt{\frac{1}{N}\sum_{i=0}^{N} V_i^2}}{\sqrt{\frac{1}{N}\sum_{i=0}^{N-1} V_i^2}}$$

V(0) and V(N) are near to zero, therefore,

$$\sum_{i=0}^{N-2} V_i^2 \approx \sum_{i=0}^{N-1} V_i^2$$

and

$$\gamma_{rms} = \frac{\sqrt{\frac{1}{N-1}} - \sqrt{\frac{1}{N}}}{\sqrt{\frac{1}{N}}} = \frac{\sqrt{N} - \sqrt{N-1}}{\sqrt{N(N-1)}}$$

When N=2500,

$$\gamma_{rms} = \frac{0.01}{2500} \times 100\% = 0.0004\%$$

Ignoring the error of digit computing, the whole measurement error originates from DMM and cycle computer error. The system error analysis is showed in Table (4).

Table (4) System error analysis

Error source	Uncertainty limit
Sampling digitizer	0.005% (DCV mode; DC-50kHz bandwidth)
Computing error	0.0004%

The total system error was computed as following:

$$\sqrt{(0.005\%)^2 + (0.0004)^2} = 0.00502\%$$

Ⅴ Conclusion

By using of sampling and computing method and high accuracy and resolution sampler and digitizer, the low frequency AC voltage was measured accurately. The error analysis result shows advantage of the solution proposed in accuracy. The actual measuring data and analysis had demonstrated its practicable and excellence in measurement process and in accuracy. Because of the limit of writing in space available, some technique and research results of DDS were not discussed in the paper. The practice of researching low freq. voltage source and the measurement results proved that DDS technique is advanced and excellent solution to low freq. signal generating.

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