Research on Differential Sampling with a Josephson Voltage Standard

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***Abstract* — This paper describes a differential sampling method that uses a commercial sampling Analog Digital Converter (ADC) and the Programmable Josephson Voltage Standard (PJVS) to measure the ac voltages provided by the Fluke 5720A calibrator. After averaging, the type A uncertainty obtained in the determination of the amplitude of a 0.7 Vrms ac voltage at 62.5 Hz is less than 1 µV.**

***Index Terms* — Differential sampling, programmable Josephson voltage standard, ac voltage measurement..**

I. Introduction

In 2013, a 10 volt PJVS produced by NIST was imported to NIM. It is able to synthesize stepwise-approximated ac voltage up to 400 Hz with amplitude up to 10 volt. Based on this system, differential sampling techniques are successfully used for the calibrations of ac voltage[1] using an Agilent 3458A voltmeter as a sampler, which is suited for waveform frequencies below 250 Hz. This paper presents a PJVS based differential sampling method which employs a commercial ADC as the sampler to sample the voltage difference between the ac waveform under test and the stepwise-approximated ac voltage generated by the PJVS. As the samples corresponding to transients can easily be removed during data processing, the accuracy of ac voltage measurements based on the differential sampling method and the PJVS system can be improved.

II. ADC Based Differential Sampling System

In this system, only the samples corresponding to the quantum voltage steps were used to reconstruct the ac voltage under test, which avoids the measurement error coming from the transitions.

Fig. 1 is the diagram showing the differential sampling measurement setup which is based on the NIST 10 volt PJVS system and an ADC sampler. The reference signal (a sinusoidal wave at the same frequency as the stepwise) for the phase and frequency locking of the Fluke 5720A is provided by an Agilent 33250 arbitrary waveform generator. All clock signals are locked to the same time base (10 MHz frequency reference). The trigger signal (pulse wave) provided by the 10 volt PJVS system via the optical fiber is used as the external digital trigger of the ADC sampler. By synchronizing the stepwise-approximated ac waveform, the ac waveform generated by the Fluke 5720A calibrator (the waveform under test) and the sampling procedure of the ADC sampler, the samples of the voltage difference are recorded and processed in order to reconstruct the fundamental and harmonics of the ac voltage under test.

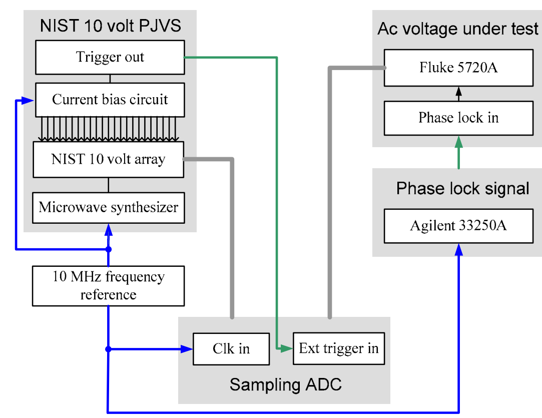

Fig. 1 Diagram of the differential sampling measurement setup.

As the stepwise-approximated ac waveform generated by the PJVS is only accurate on each constant-voltage (quantum voltage) step, the contributions from the transients between the constant steps must be removed. In the current work, only the samples around the middle of the steps are selected for the reconstruction of the waveform under test and rms voltage calculations, which means that the samples we used to reconstruct the waveform under test excludes the transient regions between the quantum voltage steps of the stepwise-approximated waveform provided by the PJVS.

The first step to reconstruct the waveform under test is to calculate the mean value of the selected differential sampling measurements on each step, and then summing the mean value with the corresponding known Josephson voltages from each sample. By fitting the fundamental and the first few harmonics of this reconstructed waveform, the amplitude and phase of the ac voltage, and the magnitude of the dc offset may be derived. The sampler acquired several data sets, each consisting of L_N cycles, where L_N could be 50, 100 and so on. The calculated values of the Fluke 5720A rms amplitude and phase are finally inferred from the measured differential signal by use of mean amplitude of the fundamental for each of the data sets.

III. Experimental Results

We did a lot of experiments to verify that this ADC sampler based differential sampling system was reliable and stable. Some important experiments were introduced in this section to

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evaluate whether the measurement results are independent of the number of cycles acquired for each data set (LN), the number of PJVS steps per period (N) and the phase of the ac voltage under test. For most of the measurements presented in this section, the calibrator was set to a constant rms amplitude of V_{rms} = 0.7 V at 62.5 Hz and the sample rate of the sampling ADC was 1 MS/s.

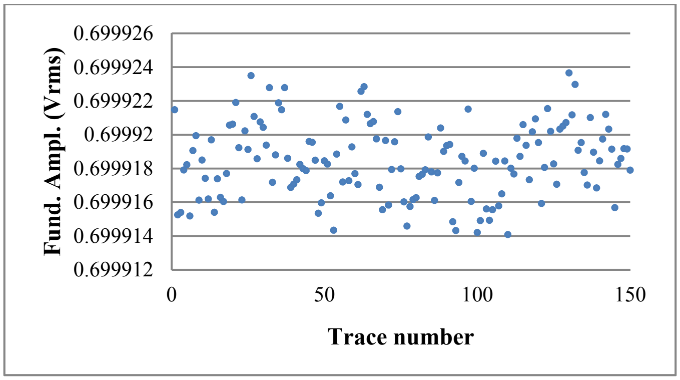

Fig. 2 Calculated values of the Fluke 5720A rms amplitude at 62.5 Hz inferred from the measured differential samples by use of an 80-step PJVS reference stepwise-approximated waveform with LN equal to 50 cycles for each trace.

Fig. 2 shows the calculated values of the Fluke 5720A rms amplitude at 62.5 Hz inferred from the measured differential samples by use of a 80-step PJVS reference stepwise-approximated waveform with L_N equal to 50 cycles for each trace. The type A uncertainty of these 150 traces is 1.8E-7 V.

The following tables present the results of three important tests that are essential for determining the potential sources of error in the differential sampling method. The measured values should be independent of the number of cycles acquired for each data set, the number of PJVS steps per period and the phase alignment.

Table 1 shows the consistent results with regard to the number of cycles acquired for each data set (L_N equals to 50, 100 and 200) where the number of PJVS steps per period is 80. Table 2 demonstrates the differential sampling measurement results with different number of PJVS steps per period (N equals to 20, 40 and 80) with L_N = 50. To check the overall stability, we repeated the previous measurement six times, varying the number of cycles acquired for each data set and the number of PJVS steps per period.

Table 1 Demonstration of the differential sampling method produces consistent results with regard to the numbers of cycles acquired for each data set (N equals to 80)

Data set number	L_N=50	L_N=100	L_N=200
1	0.6999220	0.6999201	0.6999209
2	0.6999223	0.6999181	0.6999186
3	0.6999174	0.6999191	0.6999174
4	0.6999187	0.6999182	0.6999173
5	0.6999183	0.6999191	0.6999189
6	0.6999212	0.6999208	0.6999206
Mean(V)	0.6999199	0.6999192	0.6999190
σ_n (V)	8.4E-07	4.3E-07	6.4E-07

Table 2 Demonstration of the differential sampling method produces consistent results with regard to the numbers of PJVS steps per period (L_N equals to 50)

Data set number	N=20	N=40	N=80
1	0.6999216	0.6999212	0.6999221
2	0.6999216	0.6999189	0.6999198
3	0.6999181	0.6999222	0.6999199
4	0.6999166	0.6999199	0.6999204
5	0.6999171	0.6999177	0.6999209
6	0.6999205	0.6999213	0.6999188
Mean(V)	0.6999192	0.6999202	0.6999203
σ_n (V)	9.1E-07	6.9E-07	4.6E-07

Table 3 shows the rms amplitudes measured by the ADC using PJVS stepwise-approximated sine wave with 80 steps per period, with zero relative phase, with ±0.1 degree and ±0.2 degree relative phase while keeping the other parameters of the PJVS waveform fixed.

Table 3 Demonstration of the differential sampling method produces consistent results with regard to phase misalignment

	Phase offset (degree)			
	+0.2 °	+0.1 °	-0.1 °	-0.2 °
1	0.6999207	0.6999177	0.6999217	0.6999200
2	0.6999169	0.6999170	0.6999172	0.6999184
3	0.6999216	0.6999226	0.6999209	0.6999183
4	0.6999197	0.6999228	0.6999173	0.6999164
5	0.6999168	0.6999212	0.6999193	0.6999213
6	0.6999179	0.6999206	0.6999177	0.6999178
Mean (V)	0.6999189	0.6999203	0.6999190	0.6999187
σ_n (V)	8.2E-07	9.9E-07	7.9E-07	7.056E-07

The experimental results above show that the inferred amplitude was independent of the number of cycles acquired for each data set, the number of PJVS steps per period and the phase alignment.

IV. Conclusion

This paper presents the differential sampling method researched at NIM. In this measurement system, a commercial ADC was used as the sampler to sample the voltage difference between a high-purity ac voltage produced by the Fluke 5720A calibrator and the stepwise-approximated ac voltage generated by the PJVS. The results demonstrate that this method is independent of the number of cycles acquired for each data set, the number of PJVS steps per period and the phase alignment. After averaging, the type A uncertainty obtained in the determination of the amplitude of a 0.7 V_{rms} ac voltage at 62.5Hz is less than 1 µV.

References

[1] A. Rüfenacht, C. J. Burroughs, S. P. Benz, P. D. Dresselhaus, B. C. Waltrip, and T. L. Nelson, "Precision differential sampling measurements of low-frequency voltages synthesized with an programmable Josephson voltage standard," IEEE Trans. Instrum. Meas., vol. 58, no. 4, pp. 809–815, Apr. 2009.