Precision AC Power Measurement Based on Differential Sampling System Using ACPJVS

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Abstract. This paper introduced an AC power measurement method based on differential sampling system using programmable Josephson voltage standards. The amplitude and phase measurement performance were evaluated in comparing with lock-in amplifier from angle accuracy. The results show that the accuracy is less than 0.1 μrad in measuring phase. Then, we compared the differential sampling system with harmonic power standard device by measuring Fluke 6105A in different angle phases. The results prove that the differential sampling system has good performance in measuring phase and amplitude.

1. Introduction
Following the development of the series arrays of intrinsically shunted Josephson junctions in the mid-1990s [1-3], there has been considerable work demonstrating their use as programmable Josephson voltage standards (PJVS). In addition to being essential for producing accurate and stable DC voltages, they have also been applied to AC voltage and power metrology [4,5]. Physikalisch-Technische Bundesanstalt (PTB) adopts JWS as a standard signal to calibrate the digital voltmeter (DVM) before and after the measurement to achieve two AC voltage calibration [6]. National Institute of Standards and Technology (NIST) use PJVS as a standard signal to achieve the precision measurement of the voltage signal and current signal, then use them as a standard power source to achieve a precision power measurement [7]. National institute of metrology (NIM) has developed a differential sampling system based on switching measurement, it has a good performance in AC voltage measurement [8].

In this paper, a new scheme was present in measuring AC power based on a difference sampling system (DSS), as shown in figure 1. Then we evaluated the amplitude and phase measurement performance of the differential sampling system in amplitude and angle accuracy and different angle phase measurement.

2. Measurement scheme of power measurement system
Figure 1 shows the measurement configuration for the differential sampling method, which mainly consists of three components: a sinusoidal wave voltage source of high spectral purity and stability, an ACPJVS system that provides a reference voltage waveform, and a sampling system with the purpose of data collection and signal process.
A power source supplies the voltage applied to the device under test and in parallel to the voltage transformer. Meanwhile the second channel of the power source to generate the current supplied to the load, which is also routed to the primary of a current transformer burdened with an AC shunt. The two voltages at the outputs of the voltage and current transformers, \( U_V \) and \( U_I \) with nominal RMS values of ±1 V are connected to \( V_V \) and \( V_I \) of the two differential samplers in figure 1. The PJVS generate stepwise quantum voltage supplied to two \( V_J \). Then the DSS acquire the two differential signals and send them to PC for signal processing. The ACPJVS system was developed by NIST, which enables a maximum output of 2.25 V for 17.8 GHz microwave input. The AC wave could be reconstructed by ACPJVS plus or minus differential sampling system. And, we can calculate the amplitudes and phase of them, then calculate the AC power.

### 3. Performance of amplitude and phase measurement

#### 3.1. Lock-in amplifier comparison experiment

DSS has good performance in full scale amplitude and phase measurement. In order to improve it, we compared the amplitude and phase measurement accuracy with lock-in amplifier (LIA). LIA has good performance in measuring phase and amplitude difference of two signals, and we can use the LIA to measure the RMS amplitude and phase difference of \( U_V \) and \( U_I \). The RMS amplitude of \( U_V \) and \( U_I \) could be measured by the differential sampling system, then the RMS amplitude difference can be calculated. The purpose of this experiment is to evaluate the accuracy of the differential measurement system for measuring phase and RMS amplitude, the measurement scheme is shown in figure 2. The results are shown in table 1.

![Figure 2. Phase measurement scheme](image-url)
Table 1. Phase results (a) and amplitude difference (b) of differential sampling system and LIA

|                  | LIA  | DSS  | Difference |
|------------------|------|------|------------|
| RMS difference   | 0.25 | 0.26 | -0.01      |
| (µV)             | 0.24 | 0.25 | -0.01      |
| 5 times          | 0.24 | 0.20 | -0.04      |
|                  | 0.25 | 0.26 | -0.01      |
|                  | 0.25 | 0.25 | 0.01       |
| Phase            | 0.62 | 0.68 | -0.06      |
| (µrad)           | 0.63 | 0.68 | -0.06      |
|                  | 0.62 | 0.67 | -0.05      |
|                  | 0.62 | 0.66 | 0.01       |
|                  | -0.06| -0.06| -0.04      |

Table 1 shows the RMS amplitude difference and phase between $U_\gamma$ and $U_\delta$, measured by LIA and DSS respectively. The RMS amplitude difference is directly measured by LIA, however, the DSS first measures the two RMS amplitudes and then calculates the difference of them. From the results we can see that the RMS amplitude difference and phase measured by LIA and DSS are consistent in 0.1 µV and 0.1 µrad respectively. Therefore, the DSS has a good performance in amplitude and phase measurement.

3.2. Fluke 6105A measurement

Since the standard power source which we customized has not yet complicated at present, then we use Fluke 6105A and 6106A as sources for different degrees phase measurement, more detailed evaluation will be discussed in the future. Since the Fluke 6105A and 6106A cannot drive voltage and current transformers, the current output of the Fluke 6105A and Fluke 6106A are used as signal source to generate 60 Hz 1 A rms current (the current accuracy of Fluke 6105A is relatively higher). After a 1 Ω resistance the current signal is converted into a voltage signal, the 1 Ω resistance has been traced to quantum hall resistance standard. Then we measured 0° and ±60° using differential sampling system, and harmonic power standard, which was designed by NIM [9], was used to measure Fluke 6105A and 6106A. The current measurement uncertainty of harmonic power standard is 2 µV/V ($k=1$), the phase measurement uncertainty of harmonic power standard is 3 µrad ($k=1$). The voltage measurement uncertainty of DSS is 0.3 µV/V ($k=1$), the phase measurement uncertainty of DSS is 0.2 µrad ($k=1$). The results are shown in table 2.

Table 2. Fluke 6105A measurement in different phases

| Nominal phase (°) | RMS amplitude (V) Fluke 6105A | RMS amplitude (V) Fluke 6106A | Measured phase (°) |
|-------------------|--------------------------------|--------------------------------|--------------------|
| DSS               | 0°                             | 0.999993                       | 1.000009           | -0.00019           |
|                   | 60°                            | 0.999992                       | 1.000010           | 59.99980           |
|                   | -60°                           | 0.999993                       | 1.000008           | -60.00019          |
| Harmonic power standard | 0°                             | 0.999991                       | 1.000009           | -0.00019           |
|                   | 60°                            | 0.999989                       | 1.000010           | 59.99977           |
|                   | -60°                           | 0.999990                       | 1.000010           | -60.00015          |
| Difference        | 0°                             | 0.000002                       | 0.000000           | -0.000003          |
|                   | 60°                            | 0.000003                       | 0.000000           | 0.000025           |
|                   | -60°                           | 0.000003                       | -0.000002          | -0.000038          |

It can be seen from TABLE II that the maximum RMS amplitude difference in measuring Fluke 6105A and Fluke 6106A is 3 µV, thus, the maximum RMS amplitude error difference is 3 µV/V, then the value of $E_n$ could be calculated, which is equal to 0.7. The maximum phase difference in measuring Fluke 6105A and Fluke 6106A is 0.7 µrad, then the value of $E_n$ is 0.1. Therefore, the DSS has good performance in measuring amplitude and phase in different phases, meanwhile the experiment proved that the Fluke 6105A has good
amplitude and phase stability. More detailed evaluation of power measurement will be discussed in the future.

4. Conclusion
In this paper, we introduced a power measurement method, and evaluated the amplitude and phase measurement performance of DSS. The amplitude and phase measurement between DSS and LIA is less than 0.1 μV and 0.1 μrad respectively. And the differential sampling system has good consistency, when measured phases are 0° and ± 60°, with comparing harmonic power standard.

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6. References
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