# The NIST Sampling System for the Calibration of Phase Angle Generators from 1 Hz to 100 kHz

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## Abstract

A system for calibrating phase angle standards and phase meters from 1 Hz to 100 kHz is described. A commercial dual-channel waveform sampler is used to digitize both waveforms of the generator. The phase relationship between the two signals is resolved to less than 0.001° (17 μrad) using a four-parameter sine fit. The uncertainty in phase linearity is 0.001-0.010° over the frequency range.

## I. Introduction

Programmable phase angle standards for calibrating phase meters from 1 Hz up to 100 kHz are commercially available [1]. The calibration of these standards is normally performed at cardinal points (0°, 90°, 180°, and 270°) using bridge techniques [2]. The linearity between these cardinal points is tested by offsetting both channels by fixed phase angles and remeasuring the cardinal point. While this approach is useful, it has weaknesses; i.e., the two signals are always either 0°, 90° or 180° apart. In addition, accurate phase bridges are difficult to automate.

This paper describes a new NIST calibration system based on an alternate technique of waveform sampling to measure phase. The objective of the phase measurement system is to automate and thus speed and simplify the calibration of phase standard and phase meters while maintaining as much as possible the inherent accuracy of the existing phase bridge technique.

## II. Hardware

A simplified diagram of the sampling phase measurement system is given in Fig. 1. Using a commercially available, dual-channel, 16-bit, 1 million samples/second sampling system, both waveforms are digitized over n periods of the sinusoidal signal from the phase standard. The waveform data is then transferred via IEEE-488 to the controller where the phase calculation is performed. Whereas most phase bridges allow only a single phase generator to be calibrated at a time, the sampling technique allows any reasonable number of phase generators and phase meters to be calibrated simultaneously.

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[1] *U.S Department of Commerce, Technology Administration*

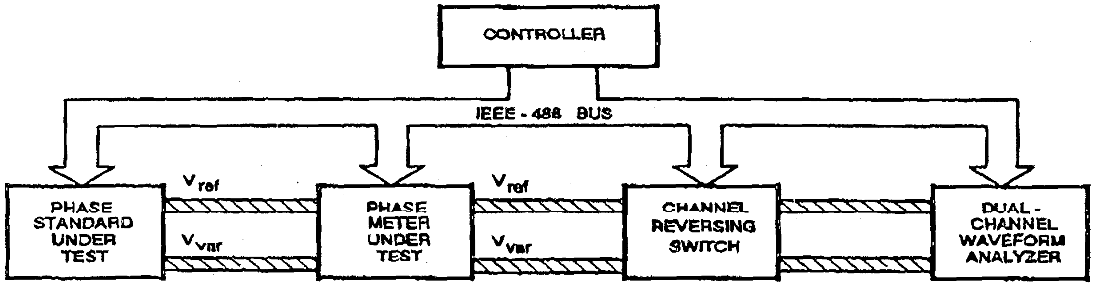


Fig. 1 Block Diagram of the NIST Sampling Phase Measurement System

## III. Measurement Technique

In order to overcome phase measurement resolution problems due to sampler timebase limitations, some sort of signal processing must be performed on the waveform data. Performing a complex FFT will provide magnitude as well as phase information for each waveform. However, since the signals are nearly sinusoidal, only the phase relationship between the fundamental components in each waveform is of interest (commonly used bridge techniques measure only this component). Therefore, if the frequency is accurately known, a least-squares sine fit is a more computationally efficient approach than a FFT. A three-parameter fit provides a good figure for dc offset, amplitude and phase.

In the most accurate phase angle generators, the output signals are digitally synthesized. The phase between these signals is shifted by modifying one of the sine lookup tables used in the synthesis process. Signals generated by this technique are as stable as the time base (typically <1 ppm/hr). However, the frequency uncertainty may be >10 ppm depending on the frequency synthesizer used. Therefore a four-parameter sine fit (including frequency) will often give better results.

The following algorithm has been employed to achieve phase resolution of <0.001° in the audio frequency range:

1. Both signals are simultaneously sampled over a large (n>500) integer number of periods.

2. A three-parameter sine fit routine [3] is used on each waveform record to come up with reasonable estimates for amplitude, phase and dc offset. Assuming a data record $y_n$ of $M$ samples, the solution of this fit is of the form

$$y_n = A\cos(wt_n) + B\sin(wt_n) + C$$

where

$w$ = the known angular input frequency.
$t_n$ = the time of each sample.

Since the solution to this fit is in closed form, only the frequency must be known for the algorithm to converge.

3. The results from (2) are then used as initial estimates in a four-parameter sine fit algorithm [3] whose solution is of the form

$$y_n = A\cos(wt_n + \theta) + C$$

The sum of squares of the error between this estimate and the measured data is given by

$$\epsilon = \Sigma\, [y_n - A\cos(wt_n + \theta) - C\,]^2$$

The routine chooses successive values of $A$, $w$, $\theta$, and $C$ to minimize $\epsilon$. Because this is a non-linear process, it is solved through iteration. These parameters must initially be chosen close enough for the process to converge in a reasonable amount of time.

4. The two input signals to the sampling instrument are reversed, and steps 1-3 are performed on this second set of data. This technique effectively cancels any differential time delay present between the sampler's input channels.

## IV. Test Results

Several tests were performed to evaluate the accuracy of the sampling scheme. First, using equal amplitude signals, the sampling phase meter was compared to the NIST phase bridge from 50 Hz to 50 kHz using a phase standard as the signal source. Next the sampling phase meter was tested for signal ratios of 10:1 over the same frequency range. The results of these tests are given in Fig. 2. For equal-amplitude input signals, the sampling scheme agrees with the phase bridge to within 0.005° over the frequency range. For the extreme case of 10:1 signal ratios, phase nonlinearity in the sampler's input circuitry causes the difference to climb to just above 0.010° near the upper frequency limits.

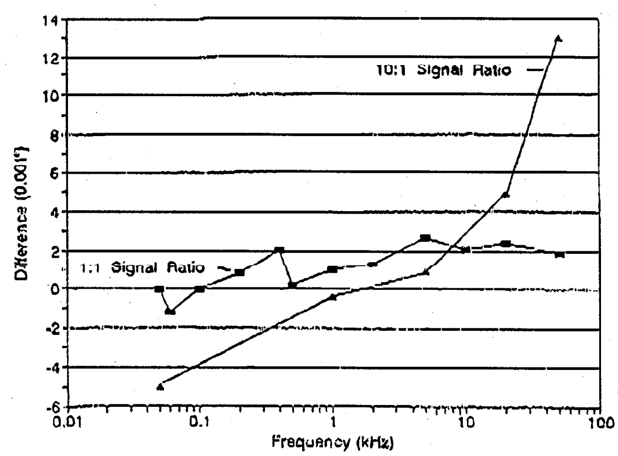


Fig. 2 Results of Intercomparison Between Sampling Phase System and Phase Bridge

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References

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