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NIST Develops Precision Phasemeter System with Pentek Boards

The National Institute of Standards and Technology (NIST) was established by Congress to assist industry in the development of technology to improve product quality, improve manufacturing processes, ensure product reliability, and facilitate rapid commercialization of products based on new scientific discoveries.

An agency of the U.S. Department of Commerce, NIST strengthens the U.S. economy by working with industry to develop and apply technology, measurements, and standards. It carries out this mission through a combination of four major programs:

- Measurement and Standards Laboratories provide technical leadership for vital components of the technology infrastructure needed by U.S. industry to continually improve its products and services;
- The Advanced Technology Program accelerates the development of innovative technologies through R&D partnerships with the private sector;
- The Manufacturing Extension Partnership offers technical and business assistance to smaller manufacturers through a network of local centers; and
- The Malcolm Baldridge National Quality Award which recognizes business performance excellence and quality achievement.

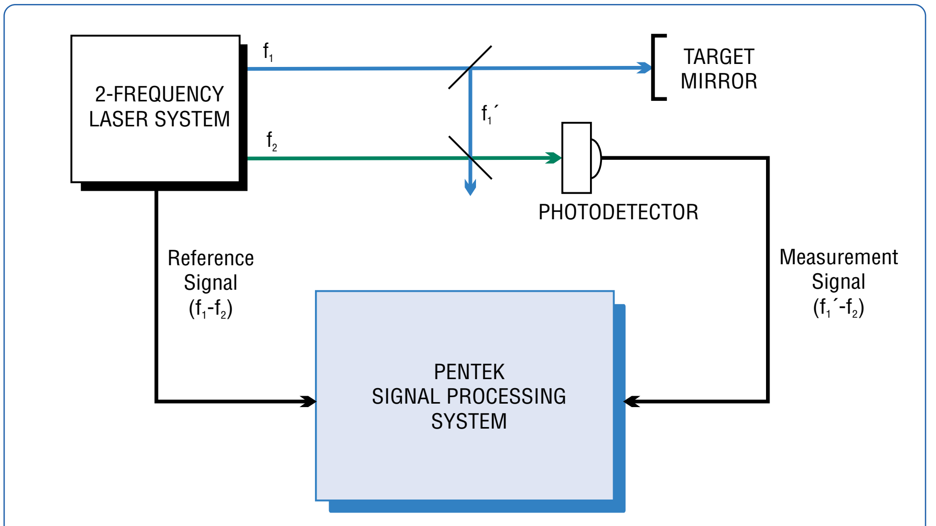

Figure 1. Interferometric Measurement System (Courtesy of NIST)

Subatomic Measurements

One of NIST's missions is to develop length-measuring capabilities and calibration standards, some of which are in the nanometer-scale regime. There is a demonstrated need by the semiconductor industry for measurement methods whose dimensions are known with nanometer-scale accuracy. Critical dimensional metrology of silicon features is an essential task in state-of-the-art semiconductor manufacturing.

The Atomic Displacement Metrology Project (ADM) at NIST is an effort to extend the technology of laser-based distance measuring interferometers into the picometer domain. Just so we can keep our units in the proper perspective,

- A micrometer (µm) is equal to 10^{-6} meter; the wavelength of visible light is about 0.5 µm
- A nanometer (nm), is equal to 10^{-9} meter; a typical atom is about 0.1 nm in diameter
- A picometer (pm) is equal to 10^{-12} meter

One essential obstacle to measuring long ranges (tens of cm) with atomic accuracy is that positioning stages generally exhibit large guiding errors at the atomic level. The ADM approach is to develop highly accurate high-bandwidth interferometers for distance measurement, and use the interferometer signals to control a mechanical compensation scheme which removes the guiding errors in real time. This implies several requirements that drive the choice of a DSP-based system. Active control of numerous degrees of freedom requires a high density system with up to a dozen data channels that can be integrated into one control system, while the real-time nature of the task requires efficient data sharing and tight integration.

Measuring Displacement with a Phasemeter

The essence of interferometric displacement metrology is to create a standing light wave by reflecting a laser beam from a target mirror, and to electronically measure the phase evolution of the reflected wave as the mirror moves. Every time the mirror moves a distance $\lambda/2$, where λ is the wavelength of the laser light, the phase of the standing wave changes by 2π. If one can resolve small phase differences, one can measure displacement with great precision.

A refinement used in the NIST ADM project is moving the signal information to very high frequency (~1 MHz). This technique allows one to make measurements near the fundamental limits allowed

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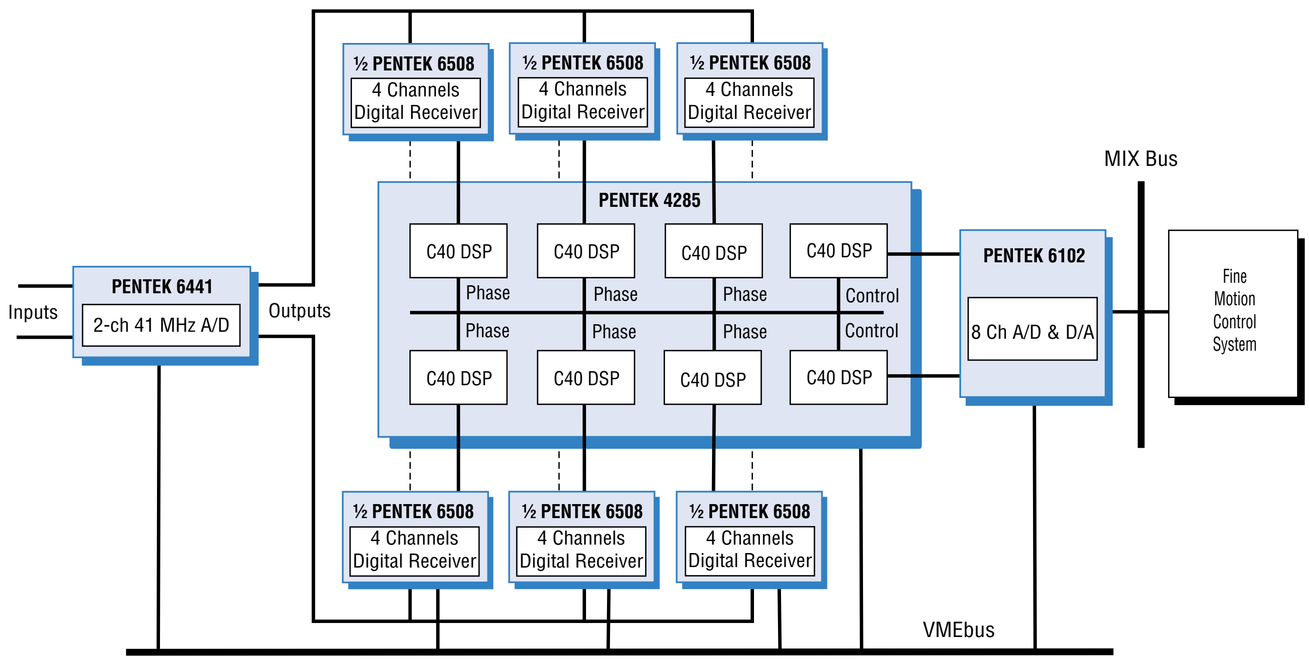

Figure 2. Simplified Block Diagram of Signal Processing System for 3-D Measurements

[Continued from page 1]

by quantum mechanics – if the electronics can handle the task.

The wavelength of the light used in the NIST work is 633 nm. Using the boards supplied by Pentek, the NIST researchers are able to measure phase with sufficient accuracy to resolve distances about 60,000 times smaller than the wavelength of their light, or on the order of 10 picometers. Equally important, these measurements can be made 10,000 times per second.

A simplified diagram of the NIST interferometric measurement system is shown in Figure 1. A sophisticated laser system produces light of two slightly different wavelengths (green and blue lines) whose optical frequencies differ by $f_1 - f_2$ (approximately 1 MHz). This frequency difference is sent to the reference input of the Pentek system. After reflection from the moving target mirror, the frequency of the light at f_1 is slightly shifted due to the mirror motion. Demodulation of the interference signal measured by the photodetector with respect to the reference signal allows the mirror displacement to be inferred in real time.

Using Digital Receivers

High throughput phase measurements suitable for heterodyne interferometer measurements have been traditionally made using time interval analyzers (TIAs). The TIA measures phase by comparing a reference signal and a measurement signal with respect to a common clock. Quantities such as phase and clock jitter can be measured. In the presence of noise, the broadband input of the TIA can register false triggers, complicating a measurement.

A digital radio system, by contrast, can be tailored to have just enough bandwidth to properly make the measurement; real and complex outputs from the digital radios can be used to measure signal magnitude and phase with respect to the sampling clock. In the case of the ADM, bandwidth requirements are directly related to mirror velocity. Since the NIST measurements can be made slowly, we can trade some measurement speed for a narrower measurement bandwidth and improved resolution.

Signal Processing

Since a phase resolution of better than $2\pi/2^{15}$ was required, the Model 6441 A/D Converter was paired with one Model 6508 8-Channel Digital Receiver. With a desired throughput of 10 kilosamples per second, a decimation rate of 4000 was used while clocking the A/D at a 40 MHz rate. The oversampling and decimation affords a few extra bits of resolution and fills the 16-bit registers of the 6508. Since the data had to be acted on in real-time, parallel processing was required. A Model 4285 Octal 'C40 Processor board provides six processors that were used for simultaneous phase measurements, while two processors were used for real-time control of the interferometers.

A conservative architecture was developed based upon the time-honored principles of differential measurements. Two digital receiver channels were employed for each phase measurement. By measuring the phase difference between two identical digital receiver and A/D channels, the sampling clock and its variations can be removed from the measurement. Likewise, any phase lags

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in the A/D front ends can also be compensated, provided the delays are well matched and stable over time.

For a single 4-beam interferometer, the eight receiver channels of the 6508 provided the capability to measure four signals at a given time, assuming that the signals are appropriately spaced apart in the frequency domain. Non-harmonically related frequencies were used to minimize A/D converter intermodulation distortion and interchannel interference.

Making 3-D Measurements

To measure 3-dimensional objects, an expanded system (Figure 2) was configured using three sets of the Model 6508 8-channel Digital Receiver. The increased number of channels provides the capability for up to 12 simultaneous phase measurements from three 4-beam interferometers (vs the previous four measurements). Such a system can measure up to six degrees of freedom, required when measuring a rigid mechanical body. Each 'C40 of the 4285 can process four receivers and make two phase measurements within the allotted time interval of 100 microseconds. The six phase-measuring DSPs put their data onto the 4285 global bus to be accessed by a 'C40 running a mechanical control loop based upon position information from the interferometers. This DSP can output voltages for position actuators on the MIX bus via a Model 6102 8-channel A/D and D/A Converter.

Figure 3. System Components Supplied by Pentek and Integrated by STS (Courtesy of NIST)

Pentek SwiftNet and the TI Code Composer were used for software development along with the TI C-compiler. LabView provides a user interface with an SBS adapter for connectivity to the system.

Figure 3 is a photograph of the system supplied by Pentek. ❑

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