MEASUREMENT TECHNOLOGY: IMMEASURABLY IMPORTANT

Robert M. White

As a theoretical physicist it took me a long time to encounter metrology, the science of measurement. But I've recently come to realize that metrology is the most critical of our "critical" technologies. I say this because most technologies depend upon the control of physical quantities.

In automobile manufacturing, for example, the Japanese maintain a 7- to 8-micron tolerance for the metal-matrix composite pistons in their new generation of engines. In the US, state-of-the-art transmission housings, engine blocks and cylinder heads have 12-micron tolerances. Tighter tolerances translate into higher quality and performance. US manufacturers are beginning to use coordinate-measuring machines on the factory floor. However, they have been unable to obtain length standards of adequate accuracy to certify and provide ongoing verification in the US. One solution has been to use the German Standards Bureau for certification of step gauges. The thought of having to send reference tools to Europe for certification should concern us.

Similarly, our capabilities to measure the line widths and registrations on both masks and wafers in semiconductor lithography processes will limit our ability to develop higher-density devices. The registration tolerance required for a 256-megabit DRAM, for example, is ± 0.08 microns.

Length is only one of the many areas where measurement technology is pushing the state of the art. In electrical goods and services, companies have a need for standards that are realizable in their own laboratories and that approach the accuracy of the fundamental standards.

For example, Hewlett–Packard's HP3458A digital multimeter, which it announced in 1989, provides 8-½-digit resolution. The development of this instrument therefore required a voltage standard with an accuracy better than several parts in 10^8. Dc voltages are often derived from a 1.018-volt saturated electrochemical cell known as a Weston standard cell, which has an uncertainty of only two parts in 10^8.

In the US, standards are kept by the National Institute of Standards and Technology (formerly the National Bureau of Standards). Hewlett–Packard learned that NIST was working on a ten-volt voltage standard using a Josephson-junction array, which had an uncertainty of one part in 10^{10}. NIST made this experimental device available to the company, facilitating the commercialization of the multimeter. A commercial Josephson-junction calibration system using a microelectronic chip is now available from RMC Inc.

Similarly, the ohm is now realized through a metal-oxide-semiconductor structure. The principle of operation is the quantum Hall effect. At liquid-helium temperature, a quantized two-dimensional electron gas is formed in the device when it is exposed to a high magnetic field. The resistance provided by such devices has been established by international agreement at 25 812.807 ohms.

Historically, timing accuracy has been driven by scientific applications. For example, in the 1970s the techniques for transferring timing information represented a limitation that the then standard atomic clock, NBS-6, with an accuracy of one part in 10^{13}, easily accommodated. The development of methods for accurately transferring time and frequency signals using satellites stimulated NIST to begin work on the next-generation standard, NIST-7. Today Hewlett–Packard sells a frequency standard, HP5071A, that has the accuracy of NBS-6. This standard is used by telecommunications companies for distributing the synchronization of their networks.

In the meantime, new scientific applications are pushing NIST to even higher accuracy. One such example is the long-term stability required to study millisecond pulsars for evidence of gravity waves (see the column by Daniel Kleppner on page 9). It appears that one can achieve an accuracy of 10^{-15} by using an optical transition in the spectrum of the mercury ion. For

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this particular ion, a long-lived second) D state results in a line width of only a few Hertz at a transition frequency of about 10^{15} Hz. To realize this line width, however, it is necessary to cool the ion to millikelvin temperatures by trapping it with radiation pressure.

Contrary to what we may have read in textbooks, metrology is not simply maintaining a platinum bar or mass in a vault. It is a dynamic field of physics that is critical to our technological infrastructure and our nation's competitiveness. Yet it does not appear on any list of critical technologies. As the national laboratories search for new missions, they should consider whether their expertise could be applied to metrology. It provides a natural linkage to industry. Metrology is nearly universally recognized as the responsibility of the Federal government. Neither industry nor academia can provide the focus and long-term financial commitment required to support metrology.

Despite the enormous interdependence between technology and metrology, NIST is the only laboratory in the country that has the mission of providing industry with measurement techniques. Furthermore, while the total NIST budget has grown considerably in recent years, the budget appropriation to fund metrology research, which is approximately \$200 million in FY 1993, has remained flat for the past 15 years, in contrast to the 4–5% annual increases seen in both industrial and other government laboratories during the 1980s.

President Bush's 1992 budget called for doubling the NIST budget for scientific and technical research over five years. However, Congress did not support this request. During the Presidential campaign, Bill Clinton also proposed to double the NIST budget. A document released by the White House on 17 February, entitled "A Vision for Change in America," contains a proposal for "doubling the amount of R&D performed in NIST labs by 1998" and increasing the total NIST budget by \$800 million, to \$1.2 billion. But the majority of the increase would go to such "extramural" programs as the Advanced Technology Program. It is important not to lose sight of NIST's historic role of supporting our technological infrastructure through metrology.

Unless the science and technology communities begin to articulate the importance of metrology, the US could lose its ability to measure physical quantities accurately enough to remain at the forefront of technology and science. ■

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