

Enhancing the Analog-Output Resolution of the Latest NI DAQ Hardware

Abstract

The latest generation of National Instruments analog I/O hardware is capable of extraordinary speeds and up to 16-bit analog output (AO) resolution. A newly-patented¹ technology, originally developed for ultra-demanding nanopositioning applications, allows users to extend their digital-to-analog (DAC) resolution well beyond 16 bits. An example herein demonstrates waveforms with amplitudes of 0.0001V, well below one least-significant-bit (LSB) for the hardware—in fact, approaching 24 bits.

Nanopositioning overview

Nanopositioning is the science of performing controlled motions with sub-nanometer resolution. Over the past two decades, it has emerged from the laboratory and taken a firm grip on key industrial processes. Today, applications in fields as diverse as semiconductor manufacturing, disk-drive head test, life sciences, photonics and defense leverage nanopositioning as a fundamental building block. Industry leader Physik Instrumente serves all these fields with catalog and OEM products.

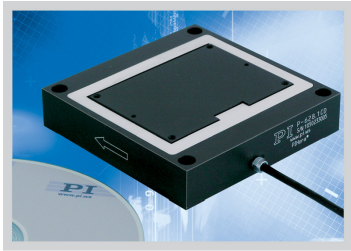


Figure 1. Nanopositioners are used in semiconductor, data-storage, life-science, photonics and defense applications.

The heart of a nanopositioner like the one in Figure 1 is a piezoelectric actuator. Sandwich structures of specialized ceramic layers separated by electrodes, these exquisitely sensitive, capacitor-like devices convert voltage into dimensional changes which can be controlled to subatomic levels. The expansion is approximately proportional to voltage and can be linearized and stabilized with the addition of a position sensor and servo controller.

The commanding voltage which animates virtually all nanopositioning applications comes from a digital-to-analog converter (DAC), a common semiconductor chip which allows digital processes to produce arbitrary waveforms and DC voltages. DACs may be characterized by their output voltage range and the number of voltage steps which may be commanded within this range. The number-of-steps is commonly characterized by the number of bits in the digital command word for the DAC's input: a twelve-bit DAC can produce 2^{12} or 4,096 voltage steps across its output range. If the output range is -10

to +10V, then each step would be 1/4,096 of the 20V range, or about 5mV.

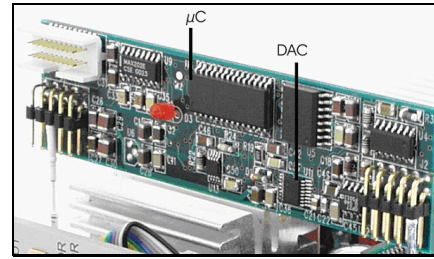


Figure 2. As seen in this photo of a nanopositioning controller, a DAC produces the voltage which controls the nanopositioner.

Similarly, if the piezo nanopositioner controller's analog input has a 0-10V range, then half of the steps can be used to command position for the DAC described above. For the example of a nanopositioner with a 100 μ m travel-range, the resulting position resolution would be 100/2,048 μ m, or about 50nm. This is a good example of DAC-limited nanopositioning, as nanopositioners are universally capable of much finer positioning resolution. (Other limiters include ambient vibration and electronic noise in the amplifier.)

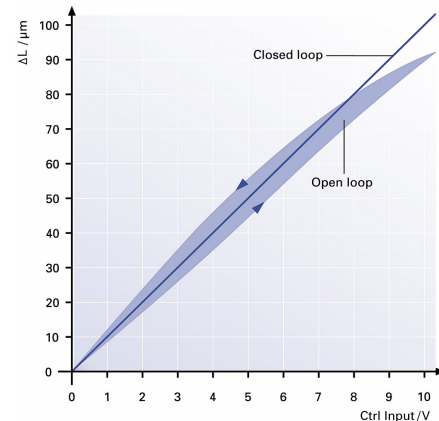


Figure 3. Piezo nanopositioners offer subatomic positioning resolutions; position is approximately proportional to voltage.

Consequently most customers choose 16-bit DAC hardware, offering 65,536 steps. Sophisticated, stand-alone or PCI digital nanopositioning controllers are also popular and can contain specialized DACs with 20 or more bits of resolution. But the deep functionality, ease-of-use and flexibility of LabVIEW™'s analog libraries creates preference for PC-based analog generation for many applications. Attractions include tight synchronization between AO and other processes including data acquisition and digital I/O, and flexible waveform generation. (To support this preference, PI has recently introduced the industry's first LabVIEW driver for analog interfacing of piezo

nanopositioners as part of its General Command Set LabVIEW library.)

Enhancing DAC resolution

Until now, the voltage resolution was a fixed property of each DAC chip. As piezo nanopositioner travel ranges increased in recent years, this has resulted in a tradeoff between resolution and travel since available analog I/O hardware tops out at 16 bits. Now, however, a newly-patented technology called HyperBit™ allows popular NI data-acquisition hardware to provide many bits of additional resolution with no loss in accuracy, bandwidth or other desirable characteristics. HyperBit is also applicable to a wide variety of applications outside of nanopositioning.

HyperBit™ is based on the observation that as fast as many DAC-driven devices like piezo nanopositioners are, today's popular DACs are faster. The technology leverages the under-utilized time-domain capability of the DAC, converting it into additional bits of resolution (Equation 1). HyperBit™ uses modulation of the least-significant bit(s) of the DAC to do this. For example, the DAC's LSBs can be dithered using pulse-width modulation at a rate exceeding the positioning system's bandwidth. The positioner acts like a flywheel to provide

smooth, stable motion with much higher resolution than the DAC's native resolution can provide, with no trade-offs (Figure 4). Many other DAC-driven devices can also benefit.

$$Bits(effective) \rightarrow Bits(DAC) + \log_2 \left(\frac{DAC_rate}{PWM_freq} \right)$$

Equation 1. Rule of thumb for resolution enhancement

Broadly applicable

This patented technology can be implemented in software or hardware. It is available for license by OEM users and is a cost-effective software option for users of PI analog I/O hardware using popular NI DAQ hardware. Example implementations include HyperBit-enabled LabVIEW subVIs, a .DLL for programmers using C or other languages, and HDL for FPGAs, as well as hardware and embedded approaches. Point-to-point and waveform actuation are supported. Generally, few or no application changes are required for implementation. (A single subVI makes the difference in Figure 4.)

Visit www.pi-usa.us for more information on HyperBit or to contact a local PI specialist.

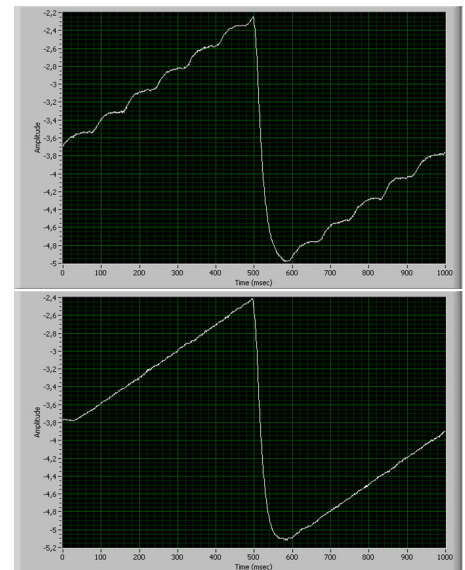
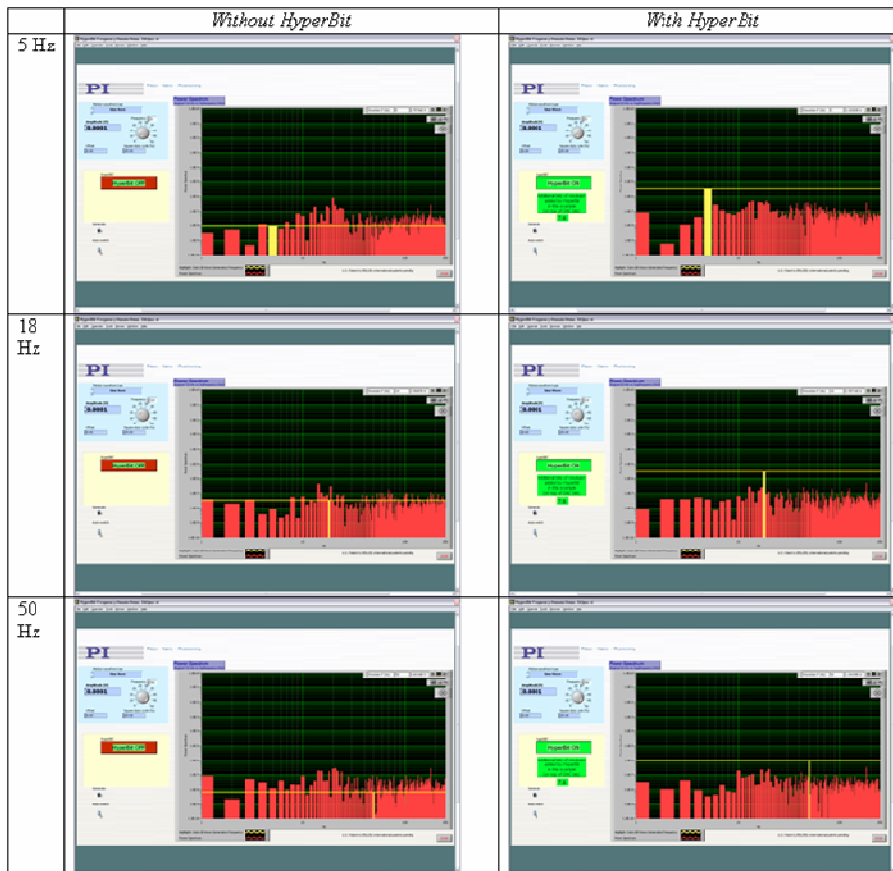


Figure 4: Demonstrations of Resolution Increase
 Above: Sawtooth nanoactuation, per laser vibrometer, showing DAC granularity (top) vs. enhanced resolution using HyperBit™ (bottom), with no loss of accuracy, stability or bandwidth.
 Left: Ambitious trade-show demonstration uses spectral analysis of sub-LSB sinusoidal actuation (yellow bars) to show 16 bit DAC approaching 24 bit resolution with HyperBit; the nanoactuation signature is clearly seen over the noise floor.

ⁱ US Pat. #6,950,050, foreign Patents pending.