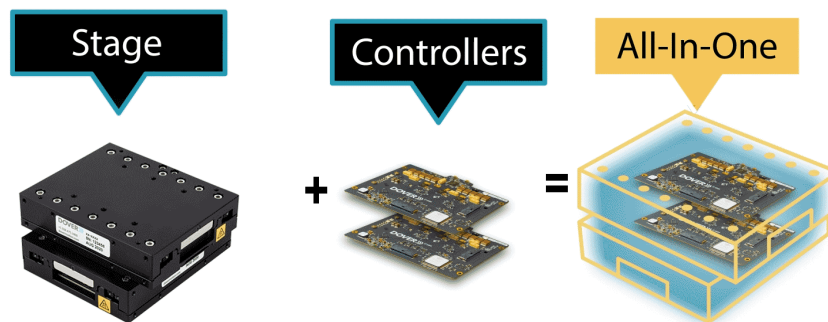


# Transforming XY Motion for Automated Microscopy

## It's time to re-think your approach to XY motion

In response to the increasing throughput, resolution, and stability requirements of automated microscopy, Dover Motion has introduced the SmartStage™ XY series for single axis or stacked XY use. The SmartStage XY is the first of its kind high performance stage where the motion controller is built-in, and doesn't require additional instrument space for motion control electronics. This multi-axis linear motor XY Stage is compact, very high performance, and is ready to be directly integrated into reliable, high-resolution automated digital microscopes. This paper introduces the SmartStage XY platform, and compares it to alternative technologies, demonstrating why it is already transforming automated digital microscopy.



**Figure 1: The Dover Motion SmartStage XY Platform**

## It's Compact - Reducing Components to Reduce Instrument Size

At the heart of many Life Science and Clinical Diagnostics instruments lies an automated digital microscope. Precision positioning is central to automated microscopy; since samples are typically hundreds of times larger than the field of view, X-Y positioning of the sample is essential. The highest performance X-Y motion systems are based on direct-drive linear motor technology, but such stages traditionally come with a lot of adjacent support components. These include a motion controller, amplifiers for each axis, encoder interpolators, and multiple cables per axis of motion. During instrument development, marketing requirements determine the allowable envelope of the final imaging instrument, which in turn puts pressure on the available space for the motion and control components. Space-claims for various subsystems, including optics, illumination, reagent storage and delivery, and temperature control aggressively compete for instrument volume. Shrinking the motion components at the expense of performance is a non-starter, and so design teams are pressed to find creative ways to fit into the available space while still achieving the required motion performance. It was precisely this challenge that Dover Motion set out to address, and our new SmartStage XY is the resulting solution.



**Figure 2: Laboratory Space is Limited, Smaller Instruments are Valued**

The SmartStage XY collapses all of the motion control components into a very compact, space-saving footprint. The traditional external controller and amplifiers are eliminated; all of the high-performance servo drive and control are built into the stage itself, with a cross-section only 25 mm high x 90 mm wide. This allows designers to reduce the volume of their linear motor-based motion subsystem by as much as 400%. No more bulky, expensive, space-consuming external controllers and amplifiers. No more complex mess of moving cables. No more challenging installation contortions. Just a single compact X-Y stage to drop into place.

Traditional Stepper XY & Controller	SmartStage™ XY Monolithic Stage

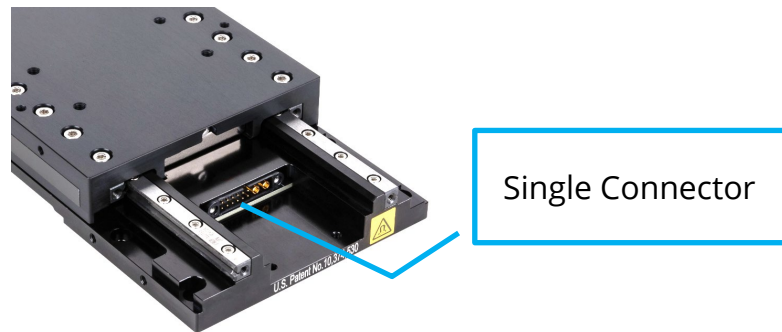
**Figure 3: Stepper Motor XY Stage Subsystem vs. Dover Motion SmartStage XY**

An often-overlooked complication is stage cabling. Cables and cable management, both physically and logistically, are problematic for design, manufacturing, and service teams. With the SmartStage XY positioner, both the lower and upper axes are powered and controlled through a **single stationary cable**. This means that multiple cables that previously had to be individually managed are merged into a single, non-moving cable which dramatically improves system reliability. This also obviates any need for bulky moving cable tracks, which corrupt position accuracy, increase motor heating, and eventually fail due to limited cable flex life. Customers that have adopted our SmartStage technology no longer have to field calls from manufacturing or field service to address stage cable issues. Another big advantage of SmartStage technology is that high-resolution analog optical encoder signals travel only a few centimeters before being digitized. In the traditional approach with external electronics, these sensitive signals are often routed for a meter or more, directly alongside noisy PWM motor cables. With SmartStage XY, crosstalk and attenuation of encoder signals is eliminated, resulting in robust position feedback and exceptional position stability.

**Table 1: The SmartStage XY is smaller, lighter, and has fewer cables**

	<b>Dover Motion SmartStage XY</b>	<b>Traditional Linear Motor Stage</b>	<b>Traditional Leadscrew Stage</b>
XY Travel (mm)	<b>100 x 100 mm</b>	100 x 100 mm	100 x 100 mm
Volume including Controls (cm <sup>3</sup> )	<b>1,477</b>	<b>2x Larger</b>	<b>4x Larger</b>
Weight (kg)	<b>2.2</b>	<b>40% Heavier</b>	<b>30% Heavier</b>
Cable Count (# of cables for XY stack)	<b>1</b>	<b>4</b>	<b>4</b>

As a result of the SmartStage XY embedding all control electronics within the stage itself, all that is required to get started is a power supply and a host computer communications port. For applications that have outgrown their stepper motor system’s capabilities and can benefit from the higher performance of a direct drive system, the SmartStage XY is ideal. Dover Motion offers plug and play communications cable kits, and provides a GUI utility, software libraries, manuals, and code examples in order to jump start system integration. Our new Motion Synergy™ API insulates users from individual low-level C Motion calls, providing a high-level of integration, with robust error checking, logging, and more. When using the Dover Motion DOF-5 Z focus axis in conjunction with the SmartStage XY to form an XYZ assembly, a single power / communications cable is all that is needed for addressable communication of all three axes.



**Figure 4: Single Connector for Power, Communications, and I/O for up to 3 axes  
It's Clean - Reducing System Complexity and Development Time**



**Figure 5: SmartStage XY stack examples (50 to 200 mm travel)**

### SmartStage XY's Embedded Motion Controller: Compact but Powerful

For all of the above focus on volumetric efficiency and vastly simplified cabling, it's important to note that these goals were realized with absolutely no compromise in performance. In fact, the embedded servo drive and control in each SmartStage XY is our highest performance motion controller to date. It closes both position and current loops at a blistering 19.53 kHz, and performs deep interpolation to 5 nanometers, with cyclical error at extremely low levels ( $\sim\pm 80\text{nm}$ ). For the most demanding applications, including very high resolution TDI scanning imaging, SmartStage XY is available in its "Ultra" version, with resolution down to 305 picometers. That's the diameter of a single aluminum atom; literally "Atomic Level Positioning"! Encoder cyclical error in the SmartStage XY Ultra series is below  $\pm 5$  nanometer!

In addition, Dover Motion has implemented an accurate triggering function as a standard feature in the SmartStage XY which allows precise synchronization of a camera, laser, or other peripheral device with the exact position of the stage. This capability is called Trigger On Position ("TOP") and is used to accurately create triggers anywhere in the move trajectory (typically but not necessarily during the constant velocity portion). In combination with Dover Motion's proprietary encoder interpolation technology, extremely accurate, high-resolution trigger spacing is achievable. Since this capability allows users to flexibly generate highly precise triggers at either periodic increments or via table-based positions (at extremely fine resolutions), it is an ideal platform for demanding applications such as TDI-CCD ("Time Delay and Integration, Charge Couple Device) scanning imaging.

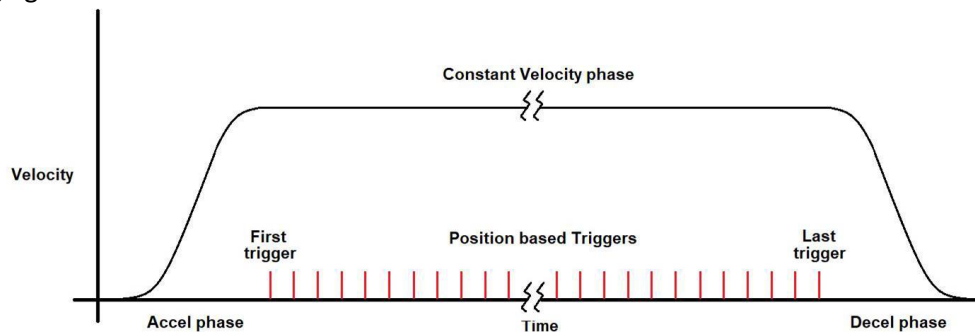


Figure 4: Typical Move Profile with Triggering

To get a better sense of just how fine TOP trigger resolution is, consider that if the nominal encoder resolution is 10 nanometers, TOP can produce over 32K different trigger resolutions between just 9 and 11 nanometers. This allows each instrument to be very fine tuned to the actual optical magnification, which can vary as much as  $\pm 5\%$ .

Another high performance feature of SmartStage XY is "PAC" (Position Accuracy Compensation). The dominant source of inaccuracy in all precision stages is usually Abbe error, which is a product of both minute angular errors in the stage guideways, and the offset between the stage's linear encoder and the sample plane. With PAC, a laser interferometer is used to measure these errors up where it counts, at the sample plane. A compensation table with these errors is then downloaded into the SmartStage XY motion controller, where it then replays those corrections on all subsequent moves, resulting in a significant improvement in overall accuracy.

SmartStage XY also supports Dover Motion's unique "RME" (Repetitive Motion Enhancement). This powerful tool allows SmartStage XY to learn and correct the following error during repetitive moves, resulting in dramatic reductions in move and settle time. This directly increases system imaging throughput, providing a valuable competitive differentiator. Moreover, RME can also freeze sample motion during the critical imaging phase, despite structural frame and vibration isolator imperfections.

### Precision Motion for Imaging Applications

Modern life-science and diagnostic instruments are becoming more precise, and their applications more powerful, as the industry continues to incorporate new enabling technologies. In turn, these technologies open up new Life Science and Diagnostic applications. Using the semiconductor industry as the quintessential example, as exemplified by Moore's Law, we find similarities in the Life Science and Diagnostics markets. In applications such as DNA sequencing, the rate of progress – measured by cost per base and gigabases per day - is advancing even faster than that which Moore laid out. As an example, super resolution optical techniques – such as structured illumination, light sheet, confocal, and other approaches - permit imaging of ultra-fine 3D nanostructures that traditional optical techniques could never achieve. These new technologies in turn require sample positioning stages to up their game, which is exactly why we developed SmartStage XY.



**Figure 5: SmartStage XYZ with four slide carrier**

For imaging based Life Science and Diagnostic applications, the alternative to TDI-CCD scanning imaging is Sequential Field Imaging (SFI), wherein the sample is moved quickly from field-to-field; brought to a stop; imaged; and the sequence repeated. In these cases, especially those with high fluence allowing for short exposure times, fast field-to-field motion and complete stability during imaging is the key to system throughput. In such systems, high servo bandwidth is a key enabling technology. We find that Dover Motion's SmartStage XY represents the real-world example of this solution. Direct drive stages can offer servo bandwidth beyond 200 Hz; often beyond the reach of what is commonly thought of as "bandwidth king", the piezo-electric actuator! This ability to effect high servo bandwidth, coupled with the SmartStage XY's stiff and well damped crossed-roller bearings, offers excellent external disturbance rejection performance far beyond that of competing technologies.

What Dover Motion has learned by collaborating with customers in high demand fields such as fluorescence microscopy, microscopy flow cells, and microfluidics is that not all imaging platforms have the same stage requirements. Being able to select the right product configuration from an available platform reduces the specification and ordering complexity.

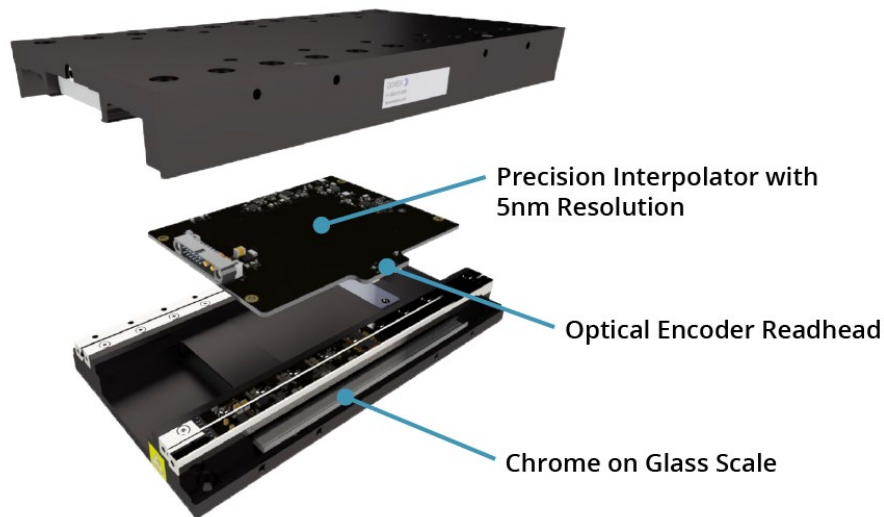


The SmartStage XY platform allows for configurable travel options to accommodate different sample sizes as shown in the table below:

**Table 2: Key SmartStage XY Specifications for Microscopy**

Travel (mm)	50	100	150	200
Position Feedback Resolution	5 nm	5 nm	5 nm	5 nm
Bi-directional repeatability. ( $2\sigma$ , $\mu\text{m}$ )	0.8	0.8	0.8	0.8
Holding Stability ( $\pm$ nm)	30	30	30	30
Maximum Velocity (m/s)	0.6	1	1	1

The high precision Dover Motion designed encoder inside the SmartStage XY is an example of how performance is elevated through this compact platform, not sacrificed. The Dover Motion precision optical encoder’s default resolution is 5 nanometers. To ensure high positioning accuracy, the encoder uses a thick and stable chrome-on-glass scale, rather than rolled-on or laser-written steel tape. The Dover encoder electronics and scale are located inside the stage to protect them from any application debris, as opposed to many stages where they are mounted externally to the stage body and exposed. The built-in interpolator also provides a reliability and cost improvement due to a reduced part count and removal of potential noise sources. Its integrated nature with the encoder electronics eliminates the traditionally cabled connection - and its consequent electrical noise source - of these critical analog signals.



**Figure 5: Exploded View of Dover Motion’s Integrated Linear Encoder**

This means higher performance specifications including speed, accuracy, coordinated motion and repeatability can be met while downsizing the consumed space. By embedding what used to be multiple cables and external electronics, the control is seamless, and performance-optimized for low noise. The result is ultra-high stage performance with 5nm resolution and no backlash (a typical leadscrew stage has  $\pm 5 \mu\text{m}$  bi-directional repeatability due to backlash in the nut). Since this direct drive method is extremely stable, it provides accurate and repeatable performance that cannot be achieved using stepper architectures.

**Table 3: Comparison of Stage Speeds**

	<b>Dover Motion SmartStage XY</b>	<b>Traditional Linear Motor Stage</b>	<b>Traditional Leadscrew Stage</b>
XY Travel (mm)	100 x 100 mm	100 x 100 mm	100 x 100 mm
Velocity (mm/s)	1,000 mm/s (@ 0.1 $\mu\text{m}$ resolution)	<b>300 mm/s</b> (@ 0.1 $\mu\text{m}$ resolution)	<b>40 mm/s</b> (with 2mm pitch leadscrew)

**It’s Integrated – Reducing the Overall System Cost and Risk**

The majority of development teams estimate a cost of around \$5k per axis for direct drive motion in a BOM. This is a logical assumption based on experience of selecting stages, linear motors, external controllers, motor drive circuits, encoders, limit and home input circuits, and cables together. However, with an integrated solution this assumption is no longer valid as the cost is significantly lower when looking at the XY axes combined. Table 4 shows an example of how the quantity of orderable components is reduced by over 75%. In addition to the cost benefit, the simplicity and reduced part count results in less inventory, less purchasing complexity, and increased reliability.

**Table 4: Example of Traditional XY Stage BOM vs. Dover Motion SmartStage XY**

	<b>BOM for SmartStage XY (2 Axes)</b>	<b>BOM for Traditional XY Stages (2 Axes)</b>
XY Stages	SmartStage XY (x1)	Linear Stages (x2)
Cables & Cable Management	All-In-One (Power, Communications, I/O Cable) 36308-040 (x1)	Encoder Cables (x2) Motor Cables (x2) Controller to Drive Cables (x2) Cable Track (x1)
Controller	N/A, built-in	Controller (x1)
Motor Drive	N/A, built-in	Drive Amplifiers (x2)
<b>Total</b>	<b>Item Count: 2</b>	<b>Item Count: 9</b>

The cost of the components is one factor, but development schedule as well as cost to program and integrate are additionally important factors. Dover Motion provides tools and support such as GUI-based tuning tools and our Motion Synergy™ API libraries with programming examples which can be leveraged for faster commissioning and integration. The software utilized in the SmartStage XY is homogeneous with all current Dover Motion control hardware, including the DOF-5 direct-drive focus stage. SmartStage XY supports multiple communication options, including RS-232, RS-485 and CAN. Further, Dover Motion has unparalleled experience and expertise in offering application-tailored solutions and in supporting customer programming.



### **SmartStage XY – Compact, Clean, and Fully Integrated**

With more than 50 years of experience providing precision motion for life science, diagnostics, and other high tech industries, Dover Motion understands the challenges and nuances of developing a successful automated imaging instrument. The experts at Dover Motion merged customer feedback with precision design expertise to develop the SmartStage XY, a linear stage platform that dramatically increases throughput in automated microscopy, while substantially decreasing the required space within the instrument. The motion controller and servo drive are built inside the SmartStage positioner itself, providing a complete high-performance XY motion system in an ultra-compact package. This extremely clean architecture and flexibly programmable platform reduces BOM complexity and shortens product development time. As a result of this tightly integrated platform, the overall system cost and program risk is substantially reduced.

For more information on the Dover Motion SmartStage XY Linear Positioner, or its powerful Trigger On Position capability, visit: <https://dovermotion.com/smartstagesxy>.

This white paper was collectively written by the team at Dover Motion.