# Nested Space-Filling Curves and Enabling Technology for Compressive Sensing and Electron/Ion Lithography

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For electron and ion beam lithography systems, it is essential to send patterns in a high bit depth to account for microscope distortions and at high temporal accuracy to achieve the best resolution and results from proximity effect correction. This is true for traditional binary patterns, grayscale lithography, and 3D milling and deposition applications. By combining a 20-bit 1 MHz "slow" Digital to Analog Converter (DAC) with a 16-bit 50 MHz "fast" DAC driven by a field programmable gate array (FPGA), PanoScientific has effectively created a 20-bit 50 MHz DAC for appropriate pattern types.[1] This "Dual-DAC" configuration allows for accurate positioning across large scan areas with precise sub-pixel distortion corrections. [Figure 1]

To make the best use of this hardware, traditional scan patterns are inadequate. In order to meet these impressive specs, the beam must not be allowed to move its full deflection in a short period of time, as typically seen during the "flyback" period of a raster scan. Instead, a family of traditional and modified Space-Filling Curves (SFC) are used to steer the beam through the image in a continuous manner. Incidentally, this removes the need for a beam blanker. With the Dual-DAC configuration, we can superimpose nested space filling curves atop one another: One SFC on the "slow" carrier signal and another SFC on the "fast" carrier signal. [Figure 2]

By utilizing this vector scan system and nested space-filling curves new methods for charged particle lithography and milling are enabled that reduce or eliminate the need for beam blanking, and give more control over effects such as proximity effect correction and redeposition when milling. [Figure 3] This hardware also unlocks the ability to image using emerging techniques of compressive sensing (CS) microscopy. For CS, the speed of the fast DAC allows for the beam to be moved around in random and pseudorandom patterns that meet the specifications required for the effective use of various CS algorithms. The use of lower-density CS scan patterns allows existing microscopes with external scan interfaces to scan faster and with lower dosing of imaged samples. [Figure 4]

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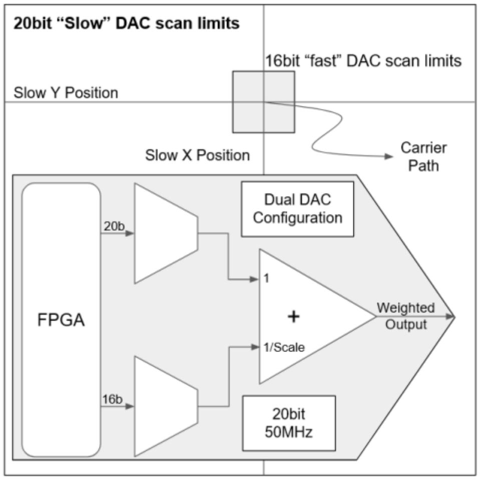

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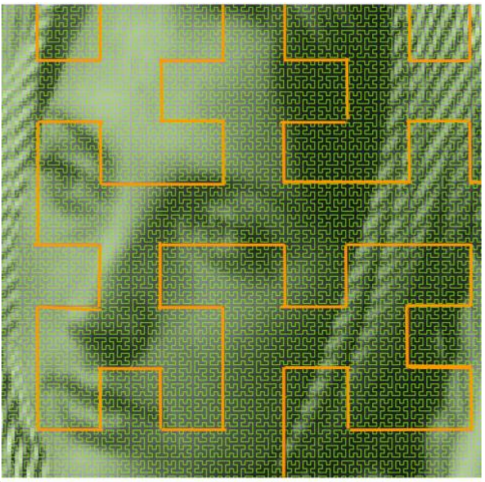

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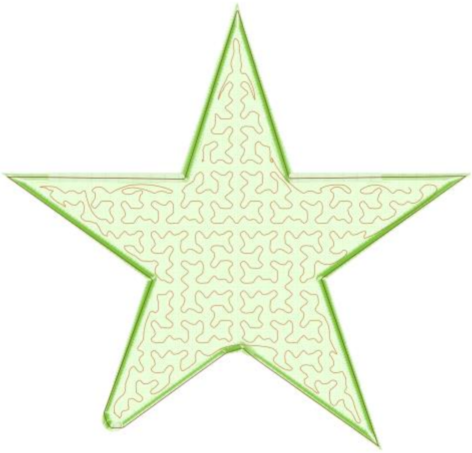

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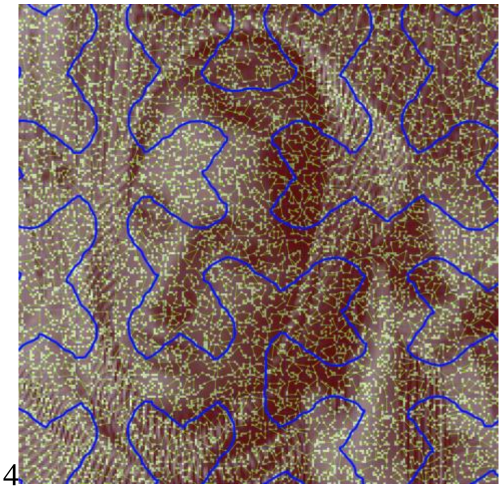

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*Figure 1: The Dual-DAC (inset) configuration enables 20bit scans at 50MHz when using appropriately selected patterns (Nested Space-Filling Curves). The slow DAC traces out the entire scan area and the fast DAC sets the fine scan.*

*Figure 2: Nested Space-Filling Curve pattern based on Hilbert Curves. Slow/Carrier signal is shown in orange and Fast signal/Beam path in green.*

*Figure 3: Lithographic infill pattern example using Nested Space Filling. Edges and infill can be defined separately for optimized proximity effect correction.*

*Figure 4: Compressed Sensing Sparse Scan using Nested Space Filling (20% scan density/80% sparsity). Red pixels are omitted from initial sparse sensing scan, Slow/Carrier signal is shown in blue and Fast signal/Beam path in green.*