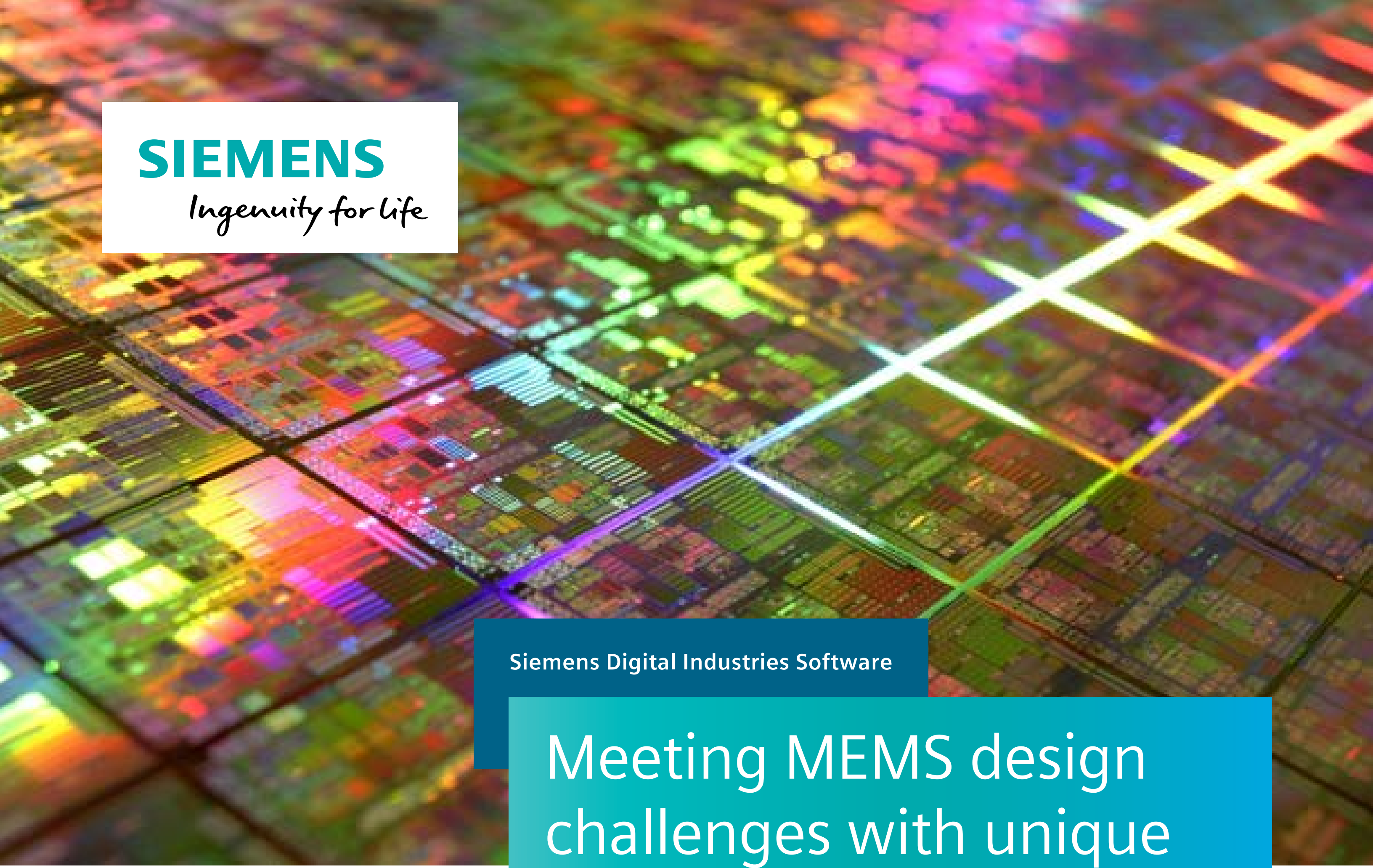

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Meeting MEMS design challenges with unique layout editing and verification features – Part 1

MEMS design

Executive summary

This two-part paper describes how and why support and ease of use for implementation of irregular shapes, including curves and all-angle polygons, is a critical criterion differentiating MEMS-oriented CAD tools from conventional IC-oriented tools. (Part 1 focuses on layout editing; Part 2 on verification.)

Nicolas Williams
product marketing manager
Siemens Digital Industries Software

Introduction

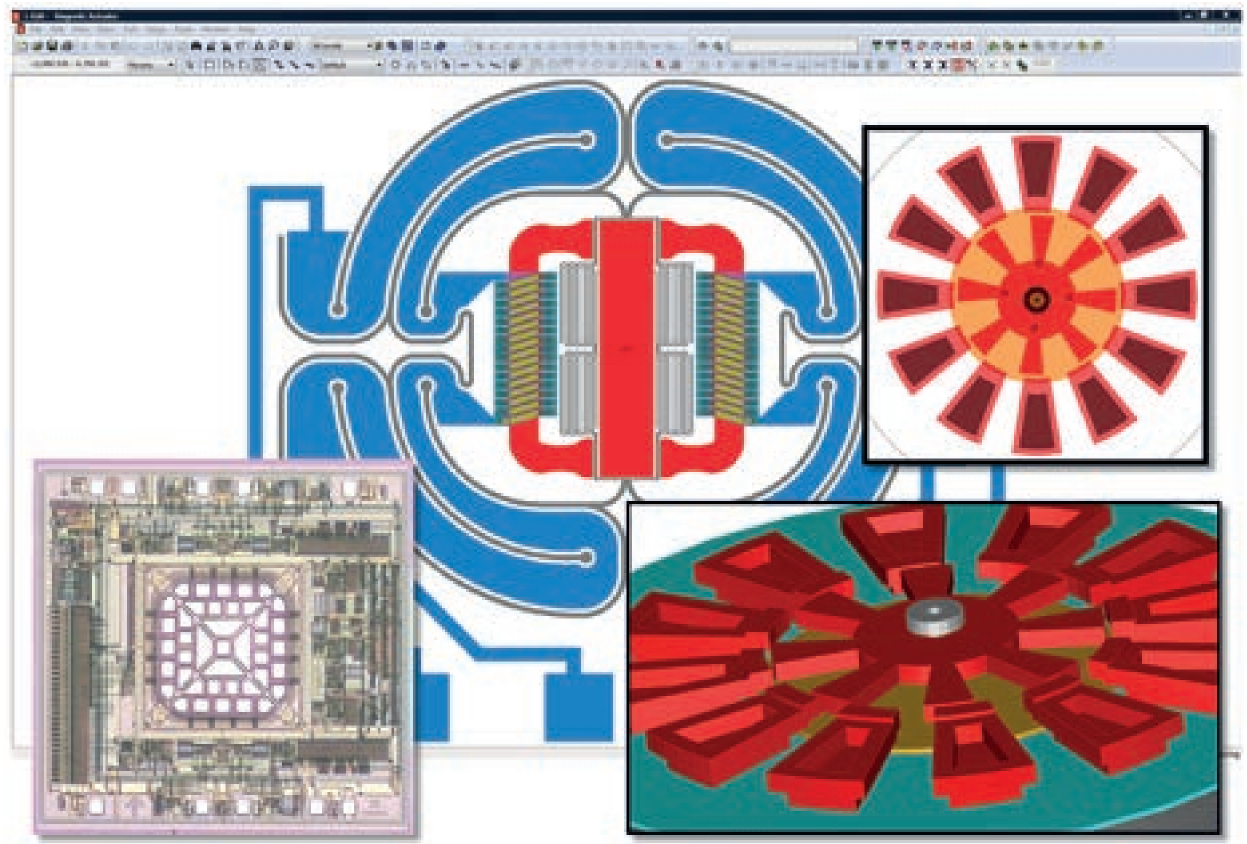


Figure 1: MEMS magnetic actuator, accelerometer and rotary side drive motor.

Microelectro-mechanical systems (MEMS) has been growing rapidly ever since it became possible to fabricate MEMS devices using modified semiconductor device fabrication technologies. Layout tools that are widely used in IC design naturally become the tool of choice for MEMS layout design. Although IC layout tools are quite mature and feature-rich for IC applications, many of them lack the capabilities to efficiently handle the challenges MEMS layout imposes. That is why unique MEMS-oriented features are needed in IC tools to address the specific requirements of MEMS layout design and to make the design process fast, easy and accurate.

A big difference between MEMS layout and IC layout is the use of unique, irregular shapes. Unlike conventional CMOS IC design, where layout shapes are usually Manhattan style (such as rectangles and rectilinear polygon) or polygon with 45-degree edges for routing, MEMS design utilizes a much broader variety of geometries, due to its wide application in mechanical, optical, magnetic, fluidic and biological fields (see figure 1). The support and ease of use for implementation of irregular shapes, including curves and all-angle polygons, becomes a critical criterion differentiating MEMS-oriented CAD tools from conventional IC-oriented tools.

Drawing curves and all-angle shapes – tori, circles, pie wedges and polygons

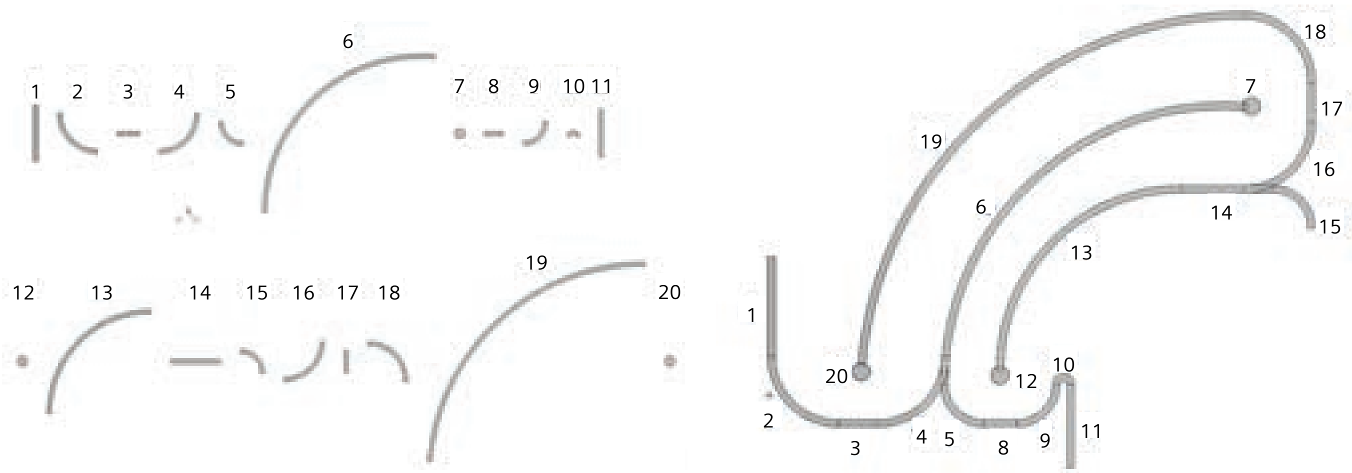


Figure 2: Complex MEMS shape stitched together from basic curved objects.

Instead of requiring the user to write C code to assemble short-length segments into multi-sided polygons to mimic curves, a MEMS-oriented CAD tool needs the ability to easily draw polygons with curved edges. For example, the Tanner L-Edit MEMS layout editor provides dedicated toolbars that quickly draw curves, such as circles, pie wedges and tori ('donuts'). The curved objects are handled as ideal circular arcs, with the sweep angle and radius as parameters editable by the user. Pieces of such curves can then be moved, rotated and stitched together to form complicated structures like a gimbal for a magnetic actuator (see figure 2).

Advanced editing operations also work on curved geometry include slicing, nibbling (cropping) and Boolean operations (AND, OR, XOR, NOT, subtract). Drawn objects can also be grown or shrunk by a specified distance, which eases the creation of coaxial shapes such as gears, wheels and microfluidic tubes. When performing these advanced editing operations, circles, pie wedges, tori and curved polygons are approximated by an all-angle polygon within the tolerance set for the manufacturing grid.

Precision placement and alignment – base point and alignment toolbar

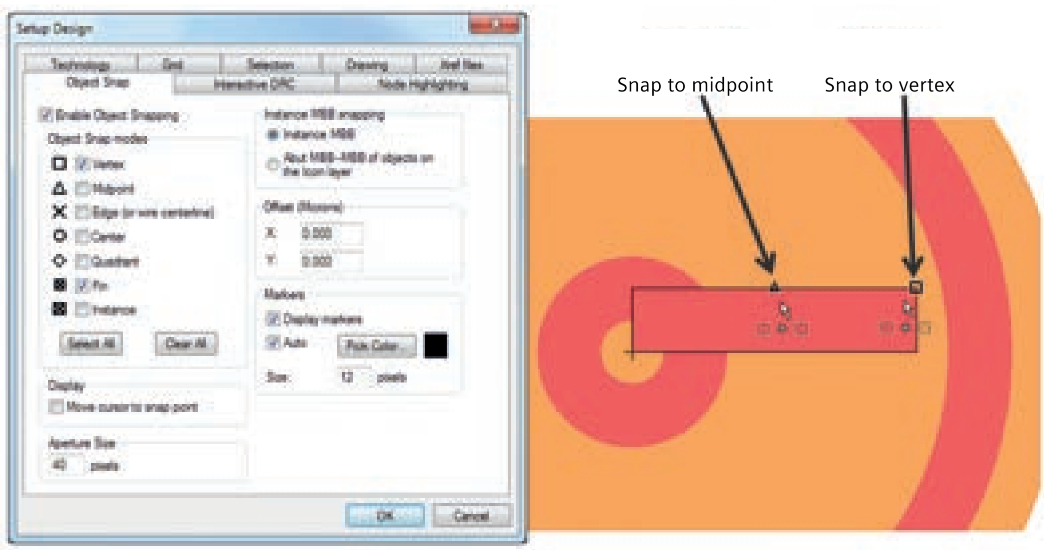


Figure 3: Snapping to different parts of objects during drawing and editing.

In addition to drawing and editing native curved objects, MEMS layout also requires the precision placement and alignment of objects to be able to quickly create complex shapes. Tanner L-Edit MEMS has a series of editing features specifically designed to meet such needs, including all-angle rotation, base point, object snapping, Move-By and the alignment toolbar.

Tanner L-Edit MEMS supports all-angle rotations of objects and instances, with a precision of six decimal points for the angle of rotation. All-angle rotations can be enhanced with the capability to create polar arrays of objects or instances where it will duplicate and rotate an object or instances multiple times around a rotation point. Polar arrays are very common in MEMS and the polar array command can speed the creation of the MEMS structure.

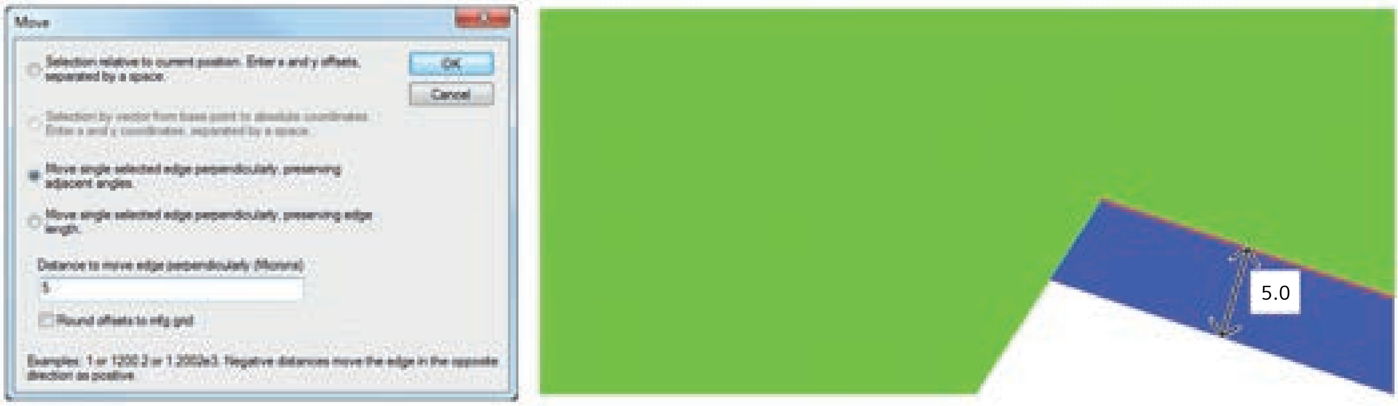


Figure 4: Moving an all-angle edge perpendicularly while preserving adjacent angles.

Base point enables a user-specified reference point for editing operations, such as move, rotate, flip, instance, cut and copy. Users can pick a base point using the cursor, or directly type in the (X, Y) coordinates of the base point. This allows users to quickly move an object and align a specific point on the object to a specific location on another object.

To help users quickly and precisely snap the cursor to a desired point, a versatile object snapping toolbar is provided, allowing snapping to an object's vertex, mid-point of an edge, anywhere on an edge, intersection, circle center, quadrant, etc. as seen in figure 3. This feature displays markers that indicate what the next drawing or editing operation will snap to and the type of the snap such as vertex, midpoint, etc. This allows the user to quickly and precisely assemble complex MEMS shaped from basic curved objects (as seen in figure 2) or to accurately edit existing objects.

Sometimes it is much easier to textually move an object or edge than graphically. Tanner L-Edit MEMS has a Move-by command that moves objects or edges by a user entered distance. Since a delta X and delta Y is entered, setting one of the delta value's to zero will constrain Move-By to edit only horizontally or vertically. Designers can also constrain the edit to move a single selected edge perpendicularly while preserving either the adjacent angles or the edge's length (see figure 4). An alignment bar supports regular object alignment tasks as well as object distribution (equal spacing between object's center or edges) and flexible object tiling. Object tiling can speed assembly of adjacent objects; for example in figure 2, objects 2, 3, and 4 were selected and tiled with a single click.

Figure 5 shows an example of how to create the majority of a complex harmonic side drive motor MEMS structure in eight easy steps. To create the structure, one creates a set of basic objects of boxes, circles, and tori. The structure can then be assembled by aligning or arraying the objects using Move-By and Polar Array.

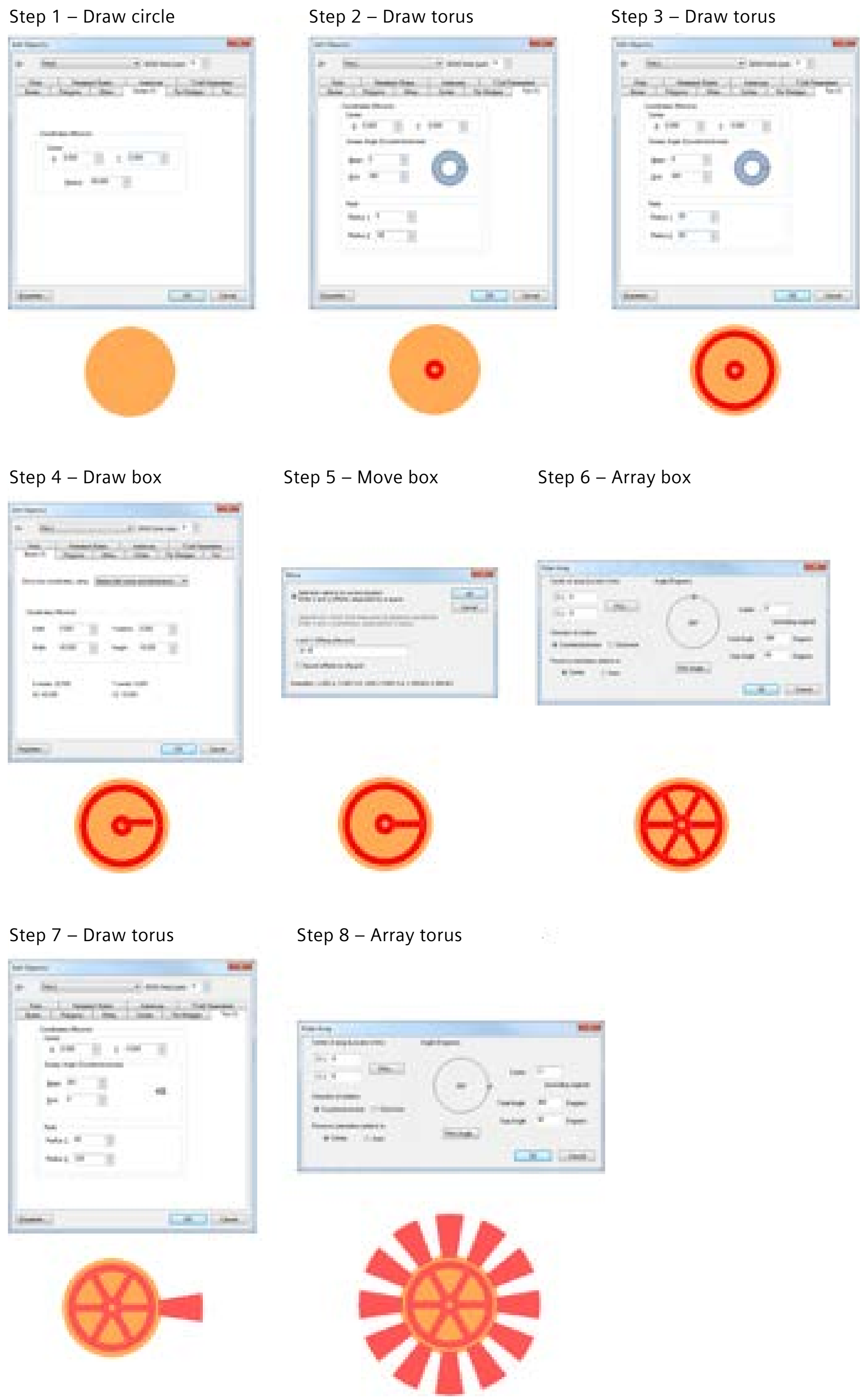


Figure 5: Creating a harmonic side drive motor in 8 easy steps.

Curve conversion to all-angle edges

Curved polygons need to be converted to all-angle polygons when doing some advanced editing operations, when running design rule checking (DRC) and when exporting to GDSII. The all-angle approximation must represent the actual curve as accurately as possible. In some CAD tools, curves are converted based on a specific number of vertices, which doesn't guarantee the precision between curves of different sizes. Tanner L Edit MEMS converts curves based on the manufacturing grid, which adjusts the number of vertices to use during conversion based on the size of the curves to have maximum precision.

To show the difference between the approach of Tanner L-Edit MEMS and other CAD tools, three circles with a 5 µm, 50 µm, and 250 µm radius were converted in figure 7 to all angle polygons using a fixed number of vertices which is common in other CAD tools. They were also converted using the approach of Tanner L-Edit MEMS. Notice that for small curves such as the 5um radius circle, both approaches do a good job approximating the curve compared to the original curve and have about the same error. For larger curves, however, the error rate increases for the fixed number of vertices method to be as much as 0.3 µm for the 250 µm circle. Since Tanner L-Edit MEMS uses the manufacturing grid to calculate the number of vertices, the error is on average, less than the manufacturing grid of 0.01 µm. Even though edges are smoothed when fabricated, this error can affect how the resulting MEMS structure performs if the error is too high. Also, this conversion error can cause problems when doing Boolean operations on curved geometry and can cause many false DRC errors.

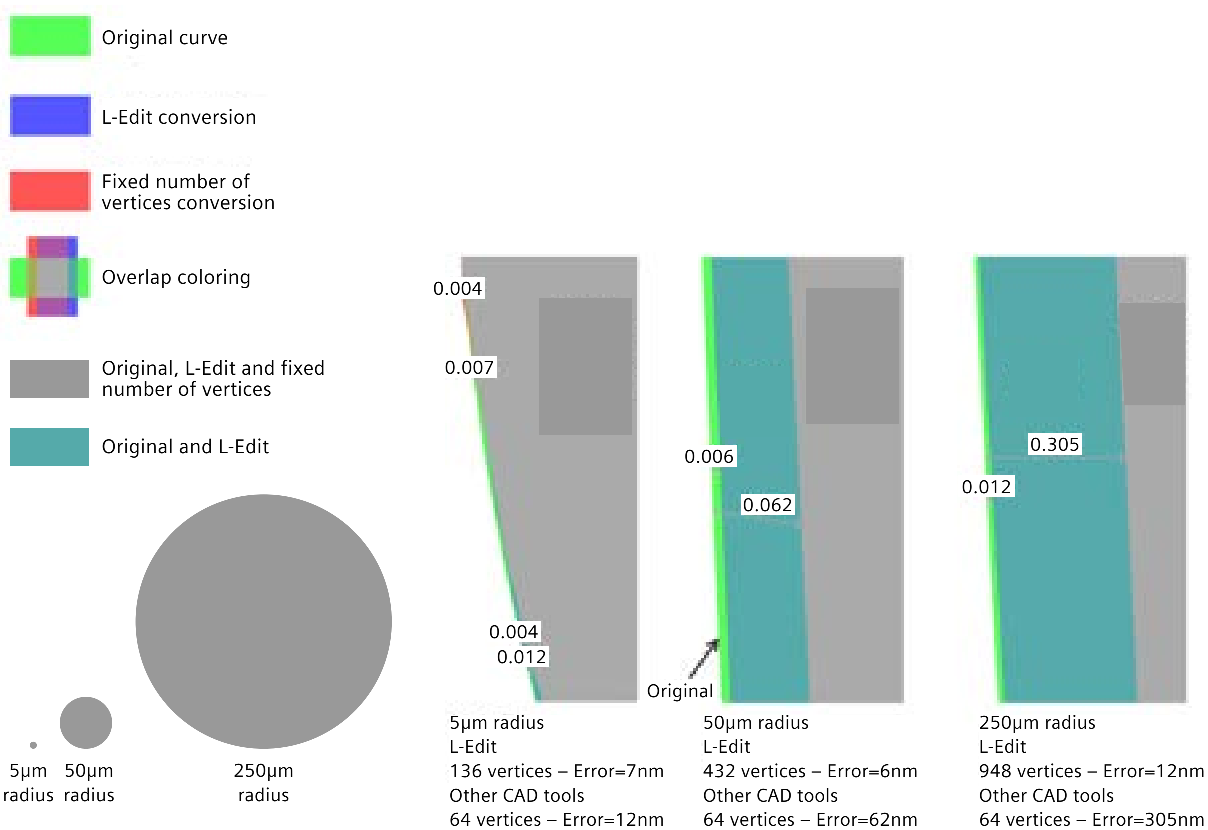
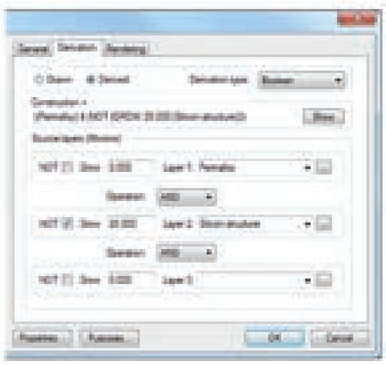
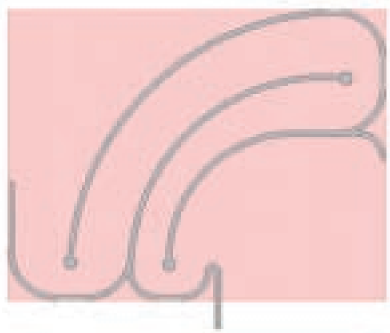


Figure 7: Curve approximation based on manufacturing grid in Tanner L-Edit MEMS provides high precision.

Using Generate Layers to create complicated shapes



Layer's derivation equation



Complex MEMS structure and red box highlighting structure extent

Generating the derived layer

Structure grown by 20µm

Grown structure subtracted from red box

Final results after trimming

Figure 8: Generating complex shape using a derived layer.

Sometimes complicated shapes are needed that can be nearly impossible to draw manually but can be easily generated from a series of Boolean operations. Tanner L-Edit MEMS supports the creation of derived layers which are Boolean operations of other layers. A derived layer can reference other derived layers, allowing the user to creating new layers from a complex set of Boolean operations of other drawn or derived layers. Once a derived layer is created, Tanner L-Edit MEMS can generate geometry on that layer, based on its derivation equation using the Generate Layers feature.

Figure 8 shows the benefit that derived layers provide when creating complex MEMS shapes. In the magnetic actuator, it is important to fill the space between the silicon structure (grey) of the gimbal but there needs to be a gap of 20 µm between the fill and the silicon structure. This can easily be done with a derived layer. First, a large box that covers the extent of the silicon structure is drawn. A new derived layer is created which will grow the silicon structure by 20 µm and subtract that from the large box previously drawn. Generate Layers is run, creating geometry on the new layer and we can then trim away any extra geometry that was generated to get the result we wanted.

Conclusion

When doing MEMS layout, a layout editor is needed with features that can handle the challenges of arbitrary shapes and structures. The effects of curved geometry and how it gets approximated affects all aspects of layout from editing to Boolean operations. The key is having the right tools to efficiently operate on curved geometry that result from MEMS structures. With the above unique features specifically developed for the purpose of MEMS design, a MEMS layout can be easily and precisely created. This makes MEMS-oriented layout tools such as Tanner L-Edit MEMS a truly indispensable assistant to MEMS designers.

Siemens Digital Industries Software

Headquarters
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 972 987 3000

Americas
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 314 264 8499

Europe
Stephenson House
Sir William Siemens Square
Frimley, Camberley
Surrey, GU16 8QD
+44 (0) 1276 413200

Asia-Pacific
Unit 901-902, 9/F
Tower B, Manulife Financial Centre
223-231 Wai Yip Street, Kwun Tong
Kowloon, Hong Kong
+852 2230 3333

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