Driving Innovation Shortens Design Cycle by 65% for First-to-Market MEMS RF Switch

Founded in 2016, Menlo Micro is an Irvine, California, technology company that leverages its design center in Albany, New York, to innovate advances in material science and develop high-performance microelectromechanical systems (MEMS) switches.

With its Ideal Switch, Menlo Micro has created a new category of electronic switches. The switches are made from custom metal alloys plated onto glass wafers with through-glass vias, technology developed in conjunction with partner Corning. The Ideal Switch replaces larger, less efficient relays and switches and eliminates compromises and trade-offs by combining the benefits of electromechanical and solid-state switches.

Utilizing its Ideal Switch technology, Menlo Micro is introducing the MM5130, an ultra-low-loss radio-frequency (RF) SP4T switch, to address high-power switching applications up to 26 GHz. The MM5130’s unique design incorporates a novel MEMS cantilever switch built with proprietary metal alloys and enclosed in a fully hermetic glass package.

The MM5130 features four channels and 25 W power handling in a miniaturized surface-mount package. The MM5130 brings significant improvements to insertion loss, power handling, and linearity. It offers greater than 99% reductions in size, weight, power, and cost for applications in aerospace / defense, automated test equipment, and communications. The best-in-class insertion loss performance, less than 0.2 dB at 6 GHz, is difficult to design, measure, and verify accurately.
Challenge: Proving Best-in-Class Insertion Loss Performance on New Technology

For the design and test environment, it was critical to achieve first-pass success from die-level design to packaged product module, integrated through the application-level printed circuit board (PCB). This process required an integrated circuit–3D electromagnetic (EM) design environment to simulate and predict the product performance at every stage. With an eye on time to market, Menlo targeted a short design cycle of three to four months for the first product.

Designing the package paths with full 3D EM simulations was critical with an extremely low-loss RF switch. Menlo needed to design everything, characterizing the modules with probing and simulating the entire design. Key to customer success was developing test fixtures and evaluation boards that demonstrate the switch’s actual performance. Menlo Micro wanted to validate performance early in the development process, so it chose to implement its own PCB de-embedding algorithms into Keysight’s PathWave Advanced Design System (ADS) software. After reaching confidence in its simulations, Menlo created device prototypes and conducted measurements by wafer probing, which demonstrated first-pass manufacturing success. Then, the engineering team performed measurements on the vector network analyzer (VNA) to compare its simulation results against actual de-embedded device measurements as proof of concept for customers.

Figure 1. MEMS switch material integration
Because of the unique material set used (MEMS and PCB) with widely differing dimensions, Menlo expected significant meshing issues during EM simulation. Menlo uses metal conductors, plated onto glass substrates, surrounded by an air cavity, with metallic conductors going through glass to get down through the package and onto the circuit board. Figure 1 shows the complexity of the material integration.

“One of the challenges is that we have two wafers bonding together,” said Dr. Xu Zhu, Menlo Micro’s director of technology. “This is a hermetically sealed cavity with a lot of metal residing on the same level. This created quite a lot of layer meshing issues due to widely different dimensions. To solve this EM problem in a 3D space, the simulator needs to cut the 3D space into numerous tiny tetrahedra to resolve the 3D structures and yet not too many for the EM simulator to handle,” with the MEMS switch sitting on top of a PCB board several inches in size.

**Demonstrating proof of concept**

The demonstration of the RF switch performance, with 0.1 or 0.2 dB of loss, is challenging to measure. The switch must be de-embedded from the evaluation board to show the end performance in a real-world environment. De-embedding removes the parasitic effects caused by the surrounding PCB structures and physical connectors. Making loss measurements on the evaluation board with a VNA adds the parasitic effects of the evaluation board to the device.

The design stage must include accommodations for de-embedding the performance of the RF switch from the board to ensure that the results measured on the Keysight PNA VNA are correlated. Figure 2 shows the switch on the evaluation board. De-embedding the board design in simulation raises the level of confidence that the device is performing to specification within the context of the test environment / module. Once manufactured, the device can be wafer probed to confirm the performance. Then the device is mounted on the evaluation board, and physical measurements are taken again using the VNA.

An important milestone was the ability to demonstrate proof of concept for early customers. Neither simulation nor wafer probing results alone are convincing proof of performance; live measurements on a live demo board are convincing proof of performance. Menlo Micro has also created several reference designs for use in various applications.
Solution: Simulation Accuracy Ensures First-Pass Success

In choosing design tools, Dr. Xu said, “we needed to consider the whole flow, from the schematic to the 3D simulations. Our engineers need to be familiar with the tools, and that’s one of the reasons that we chose PathWave Advanced Design System (ADS) as the core tool. PathWave ADS is really the core function here.”

Menlo chose Keysight, which has expertise in RF design software with circuit and 3D EM simulation as well as VNA measurements. EMPro and RFPro integrated into the PathWave ADS platform made a familiar design environment for the engineering team. Because the engineers were constantly changing and adjusting the layout in ADS, a smooth workflow from circuit layout to 3D EM simulation was critical.

EMPro and RFPro make smooth translations from the 2D layout to the 3D model files. Apart from 3D EM simulation, RFPro, with the SmartMount and Mesh Domain Optimization technologies, solved the mesh optimization challenges. Menlo Micro’s design flow includes tools from multiple vendors, so interoperability was critical. PathWave ADS worked flawlessly with Cadence APD, OrCAD, Altium, and Mentor-Tanner L-Edit, which was critical in exchanging the database with the fab. Figure 3 shows an example of a 3D EM simulated structure.
Menlo has developed an AFR algorithm in ADS to implement the entire de-embedding procedure in simulation. You can find the details in the Keysight Knowledge Center.

In the lab setup, Menlo Micro used a two-port Keysight PNA VNA. The Keysight VNA uses automatic fixture removal (AFR) techniques to de-embed the device characteristics from the fixture or evaluation board. Menlo implemented its own board de-embedding algorithms into PathWave ADS and compared the results to actual measurements on the VNA, the true measure of accuracy.

In addition, Menlo Micro’s prospective customer requested full five-port S-parameters evaluation data. Menlo used Keysight’s evaluation service to do some measurements with the AFR and correlate between two-port and five-port S-parameters to provide that key evaluation data. Keysight also provided national technical support to the design teams, spanning the design software tools and the VNA instruments. Keysight provided prompt and expert responses on the whole flow and design cycle.
Results: Design Cycle Shortened by 65% with Measurements Correlating Closely to Simulation

Previous projects of this scale lasted up to nine months for a first pass. Careful design trade-offs and EM simulation / analysis reduced the length of the first pass by 65%.

In comparing the key banner specifications against other alternatives, Menlo Micro was able to verify that its innovative technology offered significant improvements in the following areas:

- highest power density (SP4T 25 W power handling)
- lowest RF insertion loss
- best linearity / harmonics
- ultra-low power consumption

Insertion loss

Low insertion loss is the key benefit of an Ideal Switch compared with alternatives. Even a tenth of a decibel can yield a dramatic overall design performance improvement. On-wafer measurements for insertion loss went out to the full bandwidth of 20 GHz. Figure 4 shows the results.

Figure 4. Insertion loss performance
The actual measurement results closely matched the simulated results. Achieving first-pass design success was a major objective. It was a “really pleasant surprise that our design worked the first time,” Dr. Xu said. “It’s small numbers — less than 1 dB up to 12 to 15 GHz,” which is better than the performance that Menlo Micro guarantees.

Figure 5 shows the full results of the switch’s performance compared with alternatives.

<table>
<thead>
<tr>
<th></th>
<th>MM5130 SP4T FC</th>
<th>GAN (SMT) SPDT</th>
<th>PIN (SMT) SP4T</th>
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<tbody>
<tr>
<td>Max frequency</td>
<td>26 GHz</td>
<td>12 GHz</td>
<td>26 GHz</td>
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<tr>
<td>Isolation</td>
<td>&gt; 28 dB @ 6 GHz</td>
<td>40 dB @ 6 GHz</td>
<td>42 dB @ 6 GHz</td>
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<tr>
<td>Power handling</td>
<td>25 W (CW)</td>
<td>20 W</td>
<td>6.3 W</td>
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<tr>
<td>Linearity (IP3)</td>
<td>95 dBm</td>
<td>62 dBm</td>
<td>60 dBm</td>
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<tr>
<td>DC capable</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Insertion loss</td>
<td>0.2 dB @ 6 GHz</td>
<td>0.8 dB @ 6 GHz</td>
<td>0.6/1.9 dB @ 6 GHz</td>
</tr>
<tr>
<td></td>
<td>0.75 dB @ 12 GHz</td>
<td>1.5 dB @ 12 GHz</td>
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<tr>
<td>Power consumption</td>
<td>&lt; 0.08 mW</td>
<td>0.1 mA @ 40 V</td>
<td>20 mA @ -15 V</td>
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<tr>
<td>Reliability</td>
<td>&gt; 3B operations</td>
<td>Unlimited operations</td>
<td>Unlimited operations</td>
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<tr>
<td>Switching speed</td>
<td>&lt; 10 µs</td>
<td>35 ns</td>
<td>20 ns</td>
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Figure 5. Banner specification comparison

**Linearity**

Moving from silicon to glass and removing the transistor from the RF signal chain help reduce nonlinearity sources. In key applications for the switch, such as differential signaling, time-domain measurements such as eye diagram and jitter are important. Measurement results show a 1,000x performance improvement for the MM5130 SP4T compared with the alternatives.

**Power consumption**

Measurements showed up to a 99% power reduction compared with the alternatives.
Going Forward: Future Plans for 3D EM-Circuit Co-Simulation

Menlo recently moved to a subscription software licensing model to access more capabilities in the short term. The benefits of a subscription model are as follows:

• increased financial flexibility with lower upfront costs and more predictable costs
• flexibility of software mix to accommodate changing market, technology, and methodology needs within each subscription period (available only to enterprise-level agreements)
• simplified software management and deployment
• inclusion of support and software updates

The enterprise package includes RF / microwave system design, 3D EM simulation, circuit-FEM co-design, high-speed digital, and high-power electronics.

Menlo Micro is increasing the use of the newer RFPro for 3D EM–circuit co-simulation in ADS to accelerate design and verification and solve meshing issues. RFPro features a mesh domain optimization capability for the finite element method to automatically decrease the simulation space when selecting nets or components while keeping an accurate ground return path.

And finally, Menlo Micro is looking at cloud-based simulation for faster simulation cycle times. Cloud-based simulations enable easy access to scalable capacity with cloud processing clusters, particularly useful for large EM simulations. Designing a complicated 40 Gbps dual DPDT module with more than 5 million tetrahedra takes only 10 hours to complete on the cloud-based service.

Learn more at: www.keysight.com

For more information on Keysight Technologies’ products, applications or services, please contact your local Keysight office. The complete list is available at: www.keysight.com/find/contactus