Addressing new challenges in high-performance switching

As it explores recent advances in RF micro-electromechanical system (MEMS) switches, the article describes its benefits and compares performance of its latest MEMS products with conventional mechanical and electromechanical relays and switches.

By John McKillop

Continuing consumer demand for increased processor speed and higher data communications rates has been driving performance demand for electronic devices for decades. These forces are so pervasive that they have become a simple fact of life within the electronics industry—from equipment providers, to component manufacturers and system integrators. To date, the performance of established switch technologies has been able to meet the demand for increased switch performance, and switch manufacturers have largely escaped this trend. However, major applications in several key sectors of the electronics industry are driving immediate demand for significant improvements in switch performance. This includes applications in test and instrumentation equipment as well as wireless handsets and infrastructure.

New challenges

New switch challenges are evident in the test and instrumentation sector, where the clock and data rates of new ICs already exceed 1 Gbps; the maximum performance capability of most of the installed base of automatic test equipment (ATE). Because of the great expense and long development times of new high-performance ATE systems, device manufacturers have been forced to develop work-arounds—typically using switch networks on load boards to enable "loop-back" paths that allow the device under test (DUT) to test itself (Figure 1).

These applications require low loss, high-bandwidth switches (for the loop-back path) that also provide high repeatability and low resistance (for connection to the high-precision parametric test electronics within the ATE). Space constraints on load boards are also increasing, driven by the increasing number of I/O pins on electronic devices, and in turn, are driving the need for switches that are simultaneously smaller and higher performance.

While it is expected that current test requirements will be met with new generations of ATE systems, demands on signal integrity are expected to accelerate as clock and data rates increase, signal levels decline (to reduce power dissipation at increased clock rates), and pin counts continue to increase. The net result is that next-generation ATE systems will require switches that can manage higher-frequency signals, with broader bandwidth, significantly lower loss, smaller footprint, and dramatically improved resistance repeatability.

Similar trends are driving requirements for improved switching in wireless applications. New portable radio and wireless applications in handsets and base stations require switching between multiple bands with low loss over broader frequency ranges. Next-generation wireless data services will drive bandwidth requirements to Gbps levels, requiring multi-GHz bandwidths in components within the signal path. Demands for improved power efficiency will continue, driven by power and heat dissipation budgets in infrastructure applications, and size and battery life issues in handsets. The need for improved sensitivity in an increasingly noisy and crowded wireless spectrum will drive the demand for reductions in switch losses and improvements in linearity. As in ATE, these trends challenge switch technology to increase bandwidth while reducing loss, size and footprint; adding emphasis on improved power handling, linearity and cost.

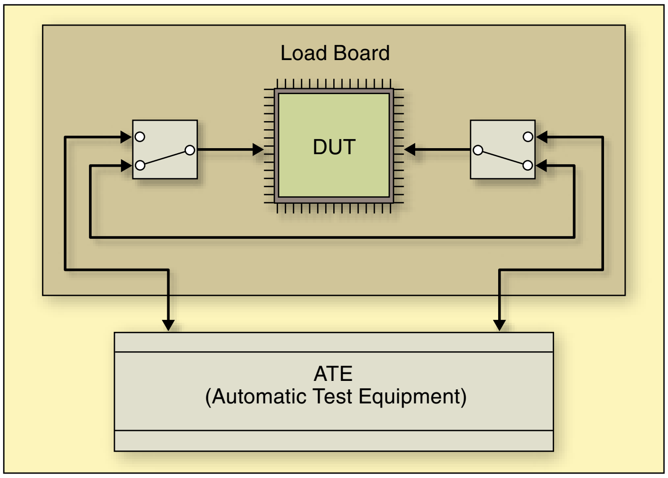

Figure 1. Loopback test schematic.

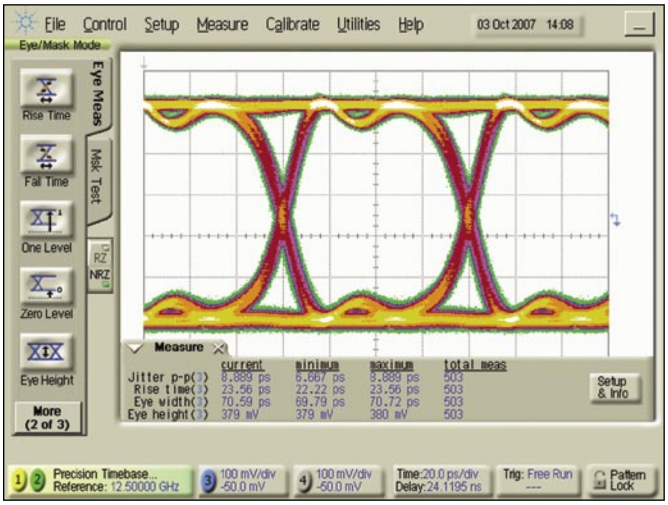

Figure 2. Eye diagram for a 12.5 Gbps signal shown after it passes through a TeraVicta's 26.5 GHz MEMS SPDT switch TT1244.

Data rates and bandwidth

A variety of design and use requirements drive the selection of high-bandwidth switches for use in multi-Gpbs data rate applica-

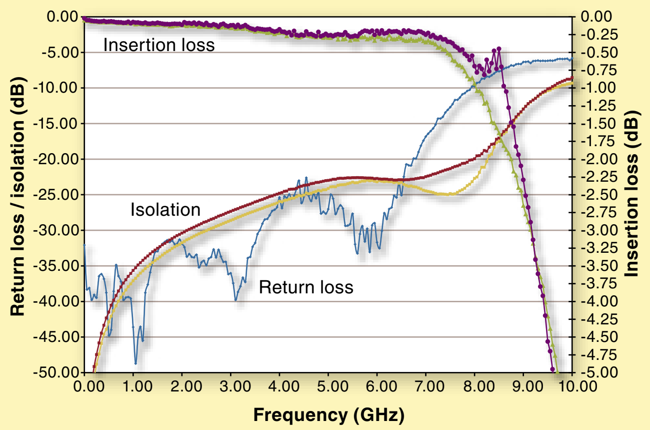

Figure 3. Performance of 7 GHz SP4T switch.

tions. High-speed digital signal integrity handbooks recommend that the 3 dB cut-off frequency of any element in the signal path be no less than 1.8 times the data rate of the digital signal—or 3.6 times the fundamental frequency (which is one half of the data rate)[1]. A transmission line with a bandwidth of 18 GHz is, therefore, recommended for the high integrity transmission of a 10 Gbps signal.

Engineers specializing in high data rate communications also use "eye diagrams" as a figure of merit for signal integrity. An open eye diagram guarantees that receiving electronics in the data path will be able to resolve clock edges and logic levels, and maintain acceptable bit error rates. Figure 2 shows an eye diagram observed for a 12.5 Gbps signal shown after it passes through a 26.5 GHz single-pole double-throw (SPDT) MEMS switch. This is in line with the 1.8x rule of thumb mentioned above, which recommends a switch bandwidth of at least 22.5 GHz.

Other data, clock and signal formats make it possible to maintain low bit error rates with lower bandwidth parts. As a result, designers using switches to connect differential data paths use cut-off frequencies that are only three times the fundamental frequency (or 1.5 x the data rate). This is supported by high-speed signal routing with TeraVicta 7 GHz MEMS switch family (3 dB cut-off frequency above 9 GHz), which shows excellent performance up to 5 Gbps in differential signal applications.

Care should be taken when applying these rules of thumb to "analog" applications where the goal is to measure the exact voltage waveforms of digital signals with minimal distortion, however. Designers of high-speed instrumentation aimed at performing this type of measurement often specify components with a minimum cut-off frequency that is at least five times the fundamental frequency of interest.

Why MEMS?

MEMS switches combine the advantages of electromechanical relays and semiconductor switches in ways that address emerging challenges in performance, size and linearity. The design, performance and reliability of MEMS switches has been discussed in detail in recent publications.[2] Key features include the use of a unique high-force disk actuator (HFDA) with low resistance Ohmic switch contacts to provide high-resistance repeatability (typically ±2 mΩ) and low insertion loss (< 0.04 dB at 1 GHz). Incorporation of a hermetically sealed gap between the switch contacts provides high-reliability operation with high isolation (> 40 dB at 1 GHz). The all-metal construction of these switches results in very high linearity (IP_3 > 75 dBm) and low intermodulated distortion(IM_3 >105 dBm). When combined with the low insertion loss of these devices this also enables continuous distortion-free operation at high RF powers (up to 15 W at 1 GHz).

Since MEMS switches are fabricated using semiconductor-manufacturing processes they can achieve very small form factors in surface-mount-compatible packages. Production can also be scaled to high volumes using established batch manufacturing techniques, enabling aggressive learning curves that rapidly drive down device costs as unit volumes increase. Adapting semiconductor-quality techniques to MEMS switch manufacturing enables delivered quality comparable to other semiconductor devices (with defect levels measured in ppm) and continued improvements in lifetime reliability.

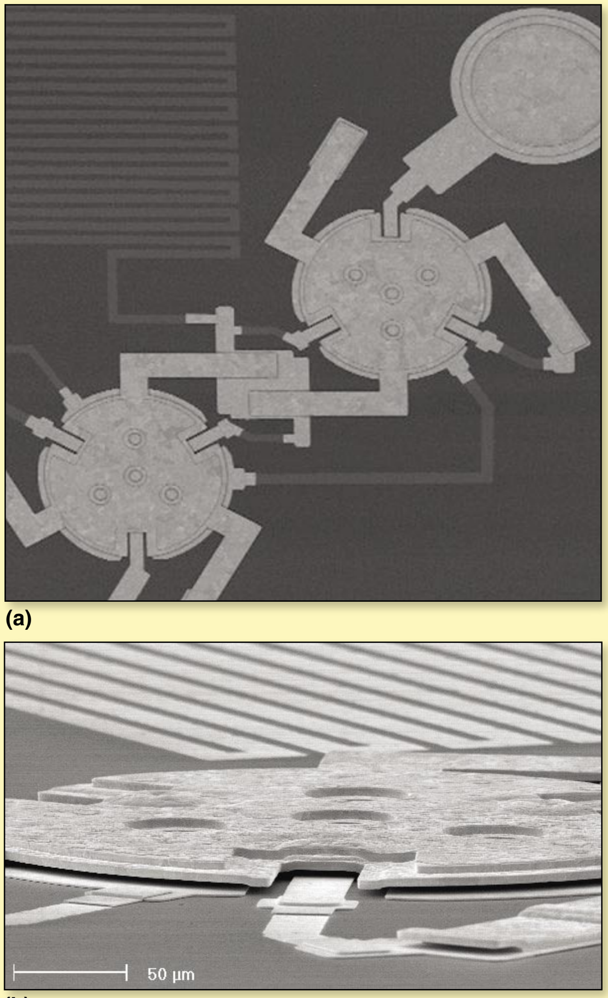

Figure 4. SEM of 26.5 GHz SPDT switch. It incorporates dual HFDA in each leg of the SPDT switch. While (a) shows top view of the SPDT, (b) portrays side view.

This allows MEMS switches to offer considerable advantages compared to other switch technologies. Compared to other mechanical relays (electromechanical and Reed relays) MEMS switches are smaller, and provide lower insertion loss, broader bandwidth, and faster switching speed. Compared to semiconductor switches (FETs and PIN diodes) MEMS switches provide lower insertion loss, improved linearity, broader bandwidth (true dc operation) and improved power handling. Most important, unlike other switch technologies, MEMS switches are at the beginning of their learning curve, and significant improvements in performance and reliability can be expected in the future.

New MEMS solutions

TeraVicta has introduced three MEMS switch products aimed at addressing emerging switch challenges. This includes the addition of a double-pole double-throw (DPDT) and SP4T switch to the existing 7 GHz switch family, and a new high-performance 26.5 GHz SPDT switch. The DPDT integrates two independent SPDT switches in a single package, reducing the size, cost and complexity of switch solutions. Incorporation of thin film resistors in the gate lines (in the device

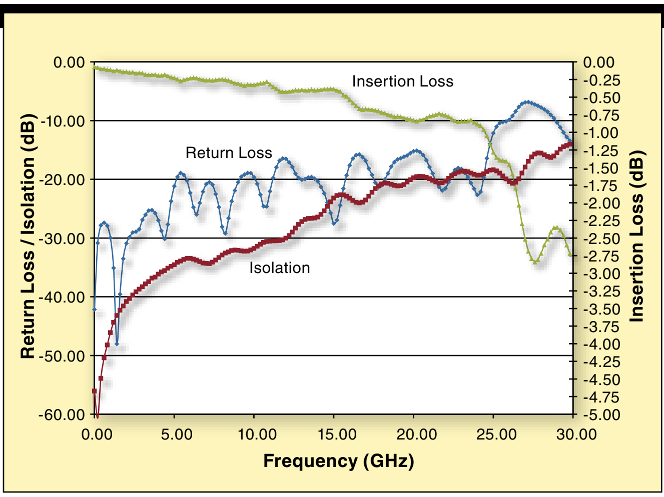

Figure 5. Typical RF performance of 26.5 GHz SPDT switch.

package) further compresses the device footprint, especially for ATE applications that can include hundreds of switches (e.g., DUT load boards). All three new switches are provided in a 3.8 mm x 5.1 mm mini-BGA chip scale package that is offered pre-balled with Pb/Sn and RoHS-compatible solder balls.

Like the DPDT, the SP4T includes integrated gate resistors to minimize the overall switch footprint. This combination allows the SP4T to provide the same functionality in a mini-BGA package (broad bandwidth, low loss, high linearity) that was previously available only from coaxial electromechanical relays. The SP4T enables high-performance fan-out for signal multiplexing in test and instrumentation applications (Figure 3). They also support band and filter switching applications in wireless systems that require low insertion loss, high linearity, and low power consumption. The compact, surface-mount package of the SP4T switch enables the construction of high-performance 4 x 4 switch matrices on a single PC board, replacing rack-based systems using coaxial switches.

The high-performance 26.5 GHz SPDT switch dramatically extends the performance of the TeraVicta switch product line. As shown in the SEM image in Figure 4, this switch design incorporates dual HFDA in each leg of the SPDT switch and integrated thin film resistors in the gate lines and bias resistors on the switch beams[3]. Use of the same HFDA technology ensures that this 26.5 GHz switch will have the same reliability, power handling and linearity as switches in the proven 7 GHz product family.

The RF performance of the 26.5 GHz SPDT is shown in Figure 5. Insertion loss is less than 0.4 dB from dc to 12 GHz, and less than 0.9 dB up to 24 GHz. Isolation is greater than 30 dB from dc to 12 GHz, and more than 18 dB up to 26 GHz. Return loss is better than 17 dB across the entire dc to 26.5 GHz switch bandwidth. Based on the discussion above, the 26.5 GHz SPDT will provide high signal integrity switching in applications up to at least 15 Gbps and will support data rates up to at least 20 Gbps in differential signal applications. This provides more than enough bandwidth to accurately test the new wave of high-performance processors, DPSs, FPGAs and memory subsystems that are incorporating high-speed interconnect protocols such as serial rapid IO (SRIO), PCI Express (PCIe), and 10 Gbit Ethernet (10GE/OC-192).

Summary

Emerging applications in digital test, instrumentation and wireless communications are driving the demand for high-performance switches. Future applications are expected to continue this trend—increasing the demand for broader bandwidth, lower loss, higher resistance repeatability, and higher linearity. And, suppliers like TeraVicta, intend to continue to capitalize on the benefits of MEMS switch technology to drive the development of new switch products to meet these needs. RFD

References

1. Howard W. Johnson and Martin Graham, "High Speed Digital Design," New York: Prentice Hall, 1993.
2. J. McKillop, "RF MEMS: Ready for Prime Time," Microwave Journal, pp. 24-38, February 2007.
3. J. McKillop and D. Goins, "High-performance K-band MEMS Switches," Proceedings of 37th European Microwave Conference, October 2007.

ABOUT THE AUTHOR

John McKillop is the chief technology officer and vice president of product development at TeraVicta Technologies, Austin, Tx. He has more than 20 years experience managing engineering and product development for companies focused on emerging technologies in MEMS, lasers and electro-optics. He holds a B. A. in chemistry from Rice University and a Ph.D. in chemistry from Stanford University.