Microwaves&RF

CHRIS KEIMEL, Chief Technology Officer,
Menlo Micro

MEMS RF Switches Help Improve RF Comms and Optimize SWaP for Satellite Platforms

Enabling next-gen wide-bandwidth, mission-critical satellite communications while meeting the SWaP constraints of spacecraft and tactical radios is a significant challenge for the space industry. Unlocking this puzzle may simply lie with the switch.

In satellite design, where each gram of mass, milliwatt of energy consumption, and cubic centimeter of occupied volume are scrutinized, the size, weight, and power (SWaP) implications of the many embedded switches have long been an important consideration for system designers.

On satellites, switches fulfill the role of routing signals in the payload and control the operation of attenuators and phase shifters that feed phased-array antennas to manage the beamforming of signals. The physical space occupied by switches impacts the dimensions of the subsystem, and their aggregated mass has launch and operational considerations. Moreover, the switches' electric power consumption places demand on the solar arrays, plus the generated heat must be appropriately managed and dissipated.

The Bottleneck in Mission-Critical Communications

Historically, system engineers have had to make difficult switch-selection decisions: Trading off specifications and radiation sensitivity between electromechanical relays (EMRs) and solid-state switches, then taking the compromises associated with those choices.

In the adverse environment of space, life expectancy is of primary importance in a situation where component failure could be fatal for the host device and issue resolution options are limited. Thus, a preference has emerged for solid-state switches whereby chip-scale size, sub-millisecond speed, and near limitless operation is paramount.

Though best in class for lifetime, solid-state switches have performance drawbacks inherent to their semiconducting materials and construction. It results in limited bandwidth, high insertion losses, poor linearity, significant passive power consumption, temperature sensitivity, and maximum power-handling capabilities of around 5 W at frequencies of interest.

Thus, the power-hungry nature of solid-state switches and EMRs impedes the development of next-generation mission-critical communication systems and prevents adoption of processor-hungry technologies that consume significant power. Furthermore, the bandwidth and power-handling restrictions of solid-state switches creates a bottleneck restricting the migration to faster data-rate, higher quality-of-service applications.

A comparable situation is evident on the ground. Although the weight of tactical radios has diminished from around 25 kg in the 1970s to around 6 kg today, the vision of a tactical radio with the size and weight of a smartphone is unfeasible using traditional switch technology. This is particularly the case when one considers that a PIN-diode filter bank alone may weigh 1 kg, with only 40% power efficiency and be the size of a laptop. We need a new type of switch technology to address the need for more efficient system design while retaining the endless desire for miniaturization.

Drawbacks of EMRs and Solid-State Switches

EMRs and solid-state switches have quite different mechanisms of control, form factors, thermal profiles, and performance characteristics. EMRs were never designed to meet the speed challenge. They were designed with simple criteria in mind — to be low loss when on and isolated when open.

EMRs rely on moving parts to change states, but these moving parts wear with every operation and become less reliable over time. In an era where energy efficiency is paramount, EMRs have another drawback besides speed: Many require a few hundred milliwatts of power to drive a coil that operates and keeps the contacts closed.

While the first semiconductor devices were designed for signal amplification, PIN diodes and gallium-arsenide (GaAs) MESFETs brought chip-scale control to RF signal applications in the 1970s and 1980s. These technologies were later joined by RF CMOS nodes and RF silicon-on-insulator (SOI) devices that helped usher in the age of handheld mobile communications.

These devices, manufactured using semiconductor materials, are aimed at addressing some of the limitations of EMRs such as slow actuation speeds, large size, and limited lifespan. However, they weren't designed to meet the full spectrum of performance demands of today's modern higher-power communications systems for tactical radios and satellites.

Radio and satellite communications typically require high energy efficiency and minimal weight as well as superior bandwidth across a broad frequency spectrum with low loss and best-in-class linearity. These needs aren't met in their entirety by either EMRs or RF solid-state switches and require a different class of switching device.

MEMS: A New Category of Switch Technology

Recently, a completely new method of switching, based on microelectromechanical systems (MEMS), has emerged. MEMS technology is nothing new given that these devices perform everyday tasks, though their presence eludes us. They control your car's airbag deployment and sense its tire pressures. They're the microphones in your handheld devices, they filter spurious communication signals, and they provide chip-based inertial stabilization for autonomous platforms.

A MEMS switch approach brings together the mechanical advantages of EMRs with the scalability of semiconductor-based technologies. Like an electromechanical switch, it maintains metal-to-metal contacts, ensuring the best possible connectivity while the switch is closed. When open, an air gap provides the highest level of insulation.

Because they're ultra-low in mass, they offer microsecond switching speeds while delivering billions of switching operations due to metal-alloy structural elements combined with platinum family series contact metallurgy. These MEMS switches are manufactured on wafers using existing manufacturing tools and techniques from the semiconductor industry. Not only do they offer scalable volume manufacturing, but they produce powerful devices in a chip-scale-packaged switching solution.

For years, MEMS switch technology has held the promise of delivering ohmic-contact EMR RF performance, with near solid-state switching speeds in a tiny chip-scale package. In this decade, they have begun to deliver on the promise.

With data demands on the rise, MEMS switches can control data rates from DC to 64 Gb/s and frequencies through K-band. Roadmaps for future MEMS switches project products that will serve W-band frequencies. With similar data rates and frequency performance needs, MEMS switches can equally serve and bring disruptive SWaP advantages to mobile radio and satellite communications.

Applying MEMS Switches in Satellite Communications

When we examine the impact of adopting MEMS switches for mission-critical communications, we can see clear advantages. For example, a beamformer typically consumes up to 25% of a satellite's energy budget. Replacing the beamformer's solid-state switches with MEMS switches can slash power consumption to less than 5% without compromising reliability.

Furthermore, solid-state switches can't compete with the frequency range over which MEMS switches provide low insertion losses. MEMS devices offer < 1 dB of insertion loss from DC to 50 GHz in a single component with near-zero leakage. It forces a rethink of the multi-band approach to payload design toward a unified ultra-broadband system, at least for the passive components.

For tactical radios, we can identify similar advantages of adopting this technology. For example, one might replace the switched filter bank with an integrated reconfigurable filter, resulting in 90% in weight savings, 90% reduction in size, and 70% fewer components. On the ground, you could equip dedicated radio operators with tactical radios that have the required features, performance, and robustness.

Linearity issues in the RF domain, even for passive components, degrade spectral purity and give rise to unintentional modulation. This translates to incorrect functioning of the beamformer (beam squint) as well as a reduction in modulation quality and subsequent errors in the digital domain.

Because the linearity of MEMS switches (IP3 > 90 dBm) can be several orders of magnitude superior to typical solid-state switches, the system can operate at higher powers without significant distortion. Thus, it improves energy efficiency and the quality of the service delivered over the system to end users.

Furthermore, the temperature range of this new category of switch is remarkable when compared to conventional relays, with a near-zero temperature coefficient. This ensures consistent performance throughout its operating temperature of −40 to 125°C, with demonstrated switching performance even down to milli-kelvin temperatures. In effect, it completely removes a historically problematic design consideration for semiconductor switches, whose performance changes significantly over temperature.

Space- and military (MIL)-grade components must meet extremely stringent reliability and environmental requirements. Now, with the emergence of the MEMS switch, which is guaranteed for 3 billion cycles and typically can achieve more than 10 billion cycles, the preference for semiconductor switches is removed. As a result, designers can take advantage of MEMS switches' optimized size, weight, and power consumption without compromising reliability.

The Overall Impact of MEMS Switches on System Design

Let's not consider the contribution of MEMS switches in isolation, but rather in context of the overall system. Lowering the insertion loss of the switch impacts the entire RF power budget of the system or subsystem, meaning that designers can relax the requirements for other components.

For example, they may enable backing off the operation point of amplifiers or using smaller amplifiers to reach the desired output. This can further decrease DC power consumption, size, weight, and cost while improving signal quality.

Semiconductors, as the name implies, are inherently lossy and that impacts the efficiency and energy budget of the host device, consuming power and generating heat, even when in the off state. It's also worth noting that MEMS switches dissipate much less power due to their lower insertion losses, resulting in switching systems with no heatsink. This eliminates yet another design consideration and further improves size, weight, and cost metrics.

The Future of Mission-Critical Communications

Even as mission-critical communications deliver new services requiring higher frequency bands, wider bandwidths, more power, and demanding quality of service, we see an overall trend toward miniaturization. In this context, we approach the limits of what's possible with traditional EMR and solid-state switch technologies.

Having reached commercial maturation, MEMS switches are set to significantly mitigate design compromises for applications ranging from satellite communications and missile guidance to intelligence, surveillance, and reconnaissance. The adoption of this technology creates new possibilities for next-generation mission-critical satellite and radio communications systems.

Because switches are the most fundamental building blocks in electronics, a new class of miniature RF MEMS switches promises to bring disruptive system advantages to next-generation communication systems.