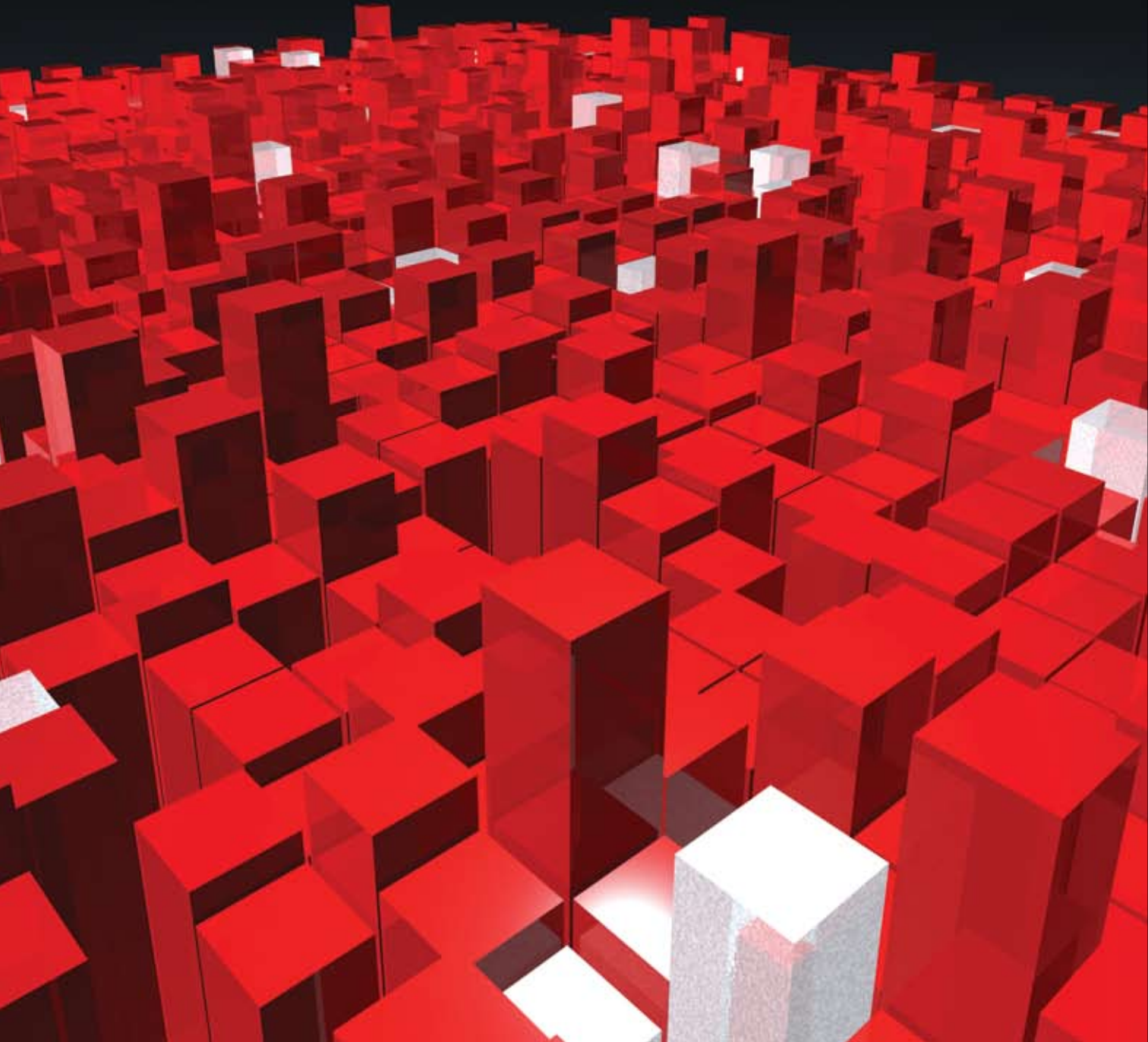


# RF

## SWITCHING OPTIONS: THE RIGHT FIT MIGHT COME WITH A LOSS



MANUFACTURERS ARE OFFERING SOI AND MEMS ALTERNATIVES TO PIN-DIODE, GaAs, AND ELECTROMECHANICAL SWITCHES FOR A VARIETY OF RF APPLICATIONS, BUT YOU NEED TO UNDERSTAND RF-SWITCH SPECS BEFORE YOU COMMIT TO A NEW TECHNOLOGY.

BY RICK NELSON • EDITOR-IN-CHIEF



Whether you are building “big-iron” RF-test equipment or tiny, multiband mobile devices, you need to route RF and microwave signals among instruments and devices under test or between antennas and amplifiers. To accomplish that task, you can turn to various solid-state implementations, including SOI (silicon-on-insulator) devices and MEMS (microelectromechanical-system) switches, both of which vendors were touting at the June IEEE MTT-S (Microwave Theory and Techniques) International Microwave Symposium. Highly integrated bulk-CMOS devices represent another alternative. However,

you need to know when those options make sense as alternatives to the more traditional electromechanical, PIN-diode, and GaAs (gallium-arsenide) FET versions. Solid-state and MEMS switches take up much less real estate and have longer lifetimes than do electromagnetic switches. Further, SOI and MEMS devices can be easier to integrate than GaAs devices with other components. Before embarking on switch selection, however, you need to understand whether the specs of the device you select will meet your application requirements.

### GETTING TO KNOW SPECS

You need to consider switch bandwidth. The switch you choose must, at its maximum operating frequency, conduct a signal. Unfortunately, when choosing a switch, you can't rely on the “3-dB-down”—that is, noise that is 3 dB lower than peak noise—rule of thumb that you might use to determine the upper operating limit of an amplifier, for example. You need to determine the acceptable

performance with respect to bandwidth in the context of the other specifications, including characteristic impedance and VSWR (voltage-standing-wave ratio), crosstalk, and isolation (Reference 1).

You should also consider whether you need to transmit low frequencies or dc. Electromechanical and FET switches generally pass low frequencies; PIN-diode switches and capacitive MEMS switches generally do not (Reference 2).

Other RF-switch specifications include characteristic impedance. You typically use a lumped-element model to represent transmission lines (Figure 1). In these models, successive infinitesimal segments of the line, which ideal transmission lines interconnect, have series resistance  $R$ , series inductance  $L$ , shunt conductance  $G$ , and shunt capacitance  $C$ . Characteristic impedance, then, is

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

For zero resistance and zero conductance, characteristic impedance is

$$Z_0 = \sqrt{\frac{L}{C}}$$

Any switch you select should present the same characteristic impedance your system exhibits to prevent signal reflections. The reflection coefficient quantifies reflections. This coefficient is equivalent to the  $s_{11}$  S parameter (Reference 3), which can contribute to a poor VSWR. With regard to VSWR, you want to know whether you are selecting an absorptive switch or a reflective switch. Absorptive versions apply a resistive shunt to ground in the off state to provide a good impedance match and minimize VSWR, regardless of switch position; reflective versions serve applications in which VSWR doesn't matter or in which you control impedance elsewhere (Reference 4).

### INSERTION LOSS, ISOLATION

Other key specs include isolation, crosstalk, and insertion loss:

$$IL = 10 \log_{10} \frac{P_{OUT}}{P_{IN}}$$

where IL is insertion loss and  $P_{OUT}$  and  $P_{IN}$  are output power and input power, respectively.

You can also represent insertion loss in terms of S parameters:

$$IL = 10 \log_{10} \left( \frac{s_{21}}{1 - s_{11}} \right)$$

The S-parameter notation to the right of the equal sign shows that the switch's insertion loss is inherent to the switch and does not depend on input mismatches. The  $1 - s_{11}$  denominator indicates that you subtract any reflected



signal that the  $s_{11}$  term represents from the normalized input-signal level before you calculate insertion loss.

Insertion loss is critical, says David Hall, an RF-product manager for National Instruments, which uses RF switches in its lineup of RF-switch-matrix test-and-measurement products. A switch must transmit your signal without undue attenuation at the frequency or frequencies of operation. If you choose a switch with too much insertion loss, he says, you may have to amplify a switched signal to make it usable, adding to system complexity and potentially introducing linearity errors.

### SPECIFYING LINEARITY

A switch can exhibit linearity errors even in the absence of amplification. Specs that indicate linearity include the 1-dB compression point and the IP3 (third-order intercept point). Measuring the 1-dB compression point involves a power sweep on the input to a device under test; when the output drops 1 dB from the level you would expect based on the small-signal response, you've reached the 1-dB compression point. IP3 measurements involve applying closely spaced tones to a nonlinear device under test, which generates third-order intermodulation products. The IP3 point is typically hypothetical because it might lie outside the safe operating region of the device under test. You obtain the IP3 using extrapolation. It occurs when the power of the third-order intermodulation products would equal that of the desired signal (Reference 5).

Other specs include crosstalk and isolation. Crosstalk represents the magnitude of a signal that couples from an active switch to an adjacent inactive switch, and isolation represents the mag-

### AT A GLANCE

▣ You need to determine the acceptable performance with respect to bandwidth in the context of the other specifications, including insertion loss, crosstalk, and isolation.

▣ Absorptive versions apply a resistive shunt to ground in the off state to provide good impedance match and minimize VSWR (voltage-standing-wave ratio) regardless of switch position.

▣ Bulk-CMOS devices offer cost advantages and fit within a small footprint.

▣ One MEMS (microelectromechanical-system) switch is rated for 100 million operations and can work for 1 billion cycles.

▣ The handset market offers high-volume opportunities for nine-throw switches going into pentaband phones.

nitude of a signal that a switch transmits from its input to its output when in the open position. A switch can be subject to various deleterious effects, including impedance mismatch, insertion loss, crosstalk, and isolation (Figure 2).

Electromechanical switches as well as PIN diodes and GaAs FET switches traditionally have excelled at meeting these specs, but each offers drawbacks. Electromechanical switches are large and can occupy significant amounts of PCB (printed-circuit-board) real estate. PIN diodes include a high-resistivity intrinsic region between their P- and N-type semiconductor regions (Reference 6). The intrinsic region becomes conductive when you forward-bias the device, essentially closing the switch to allow RF signals to pass. PIN diodes are rugged, compact devices that can handle

high voltages and currents; drawbacks include the need for external bias circuitry and the fact that the required dc bias current—and the higher the bias, the lower the insertion loss—makes them problematic for use in power-sensitive battery-operated system.

### GaAs DEVICES ARRIVE

GaAs devices remain popular. NEC markets the devices for wireless applications (Reference 7). At the June International Microwave Symposium, RF Micro Devices introduced its 6-GHz RF3021, RF3023, RF3024, and RF3025 switches, which it fabricated in its GaAs PHEMT (pseudomorphic-high-electron-mobility-transistor) technology. The symmetric SPDT (single-pole/double-throw) RF3021 and RF3025 switches feature high isolation; the RF3023 and RF3024 symmetric SPDT switches feature low insertion loss and moderate isolation. This year, Skyworks Solutions Inc introduced its Sky13317-373LE, a PHEMT GaAs SP3T (single-pole/three-throw) antenna switch that operates from 0.1 to 6 GHz. Last month, Hittite Microwave Corp introduced its GaAs PHEMT, MMIC (monolithic-microwave-integrated-circuit), SP4T (single-pole/four-throw), nonreflective HMC-C071 switch module, which targets microwave radio, VSAT (very-small-aperture-terminal), military and aerospace, fiber-optic, and broadband-test applications requiring operation from dc to 20 GHz.

GaAs FET switches have their drawbacks, however, in that they require external components in the form of blocking capacitors, and they can be difficult to integrate with other components (Reference 8). Alternatives to GaAs switches, as well as to electromechanical switches and PIN diodes, include bulk-CMOS, MEMS, and SOI switches.

### BULK-CMOS SWITCHES

Analog Devices touts its ADG9XX-family submicron, 1-GHz bulk-CMOS switches (Figure 3), which the company offers for use in the 900-MHz ISM (industrial/scientific/medical) band (Reference 9). Ray Goggin, staff design engineer, and John Quill, engineering manager, both of Analog Devices' switches-and-multiplexer-product line, cite several advantages of the devices. For exam-

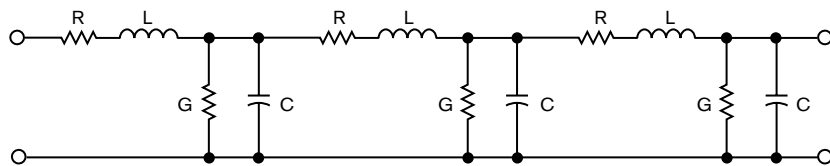
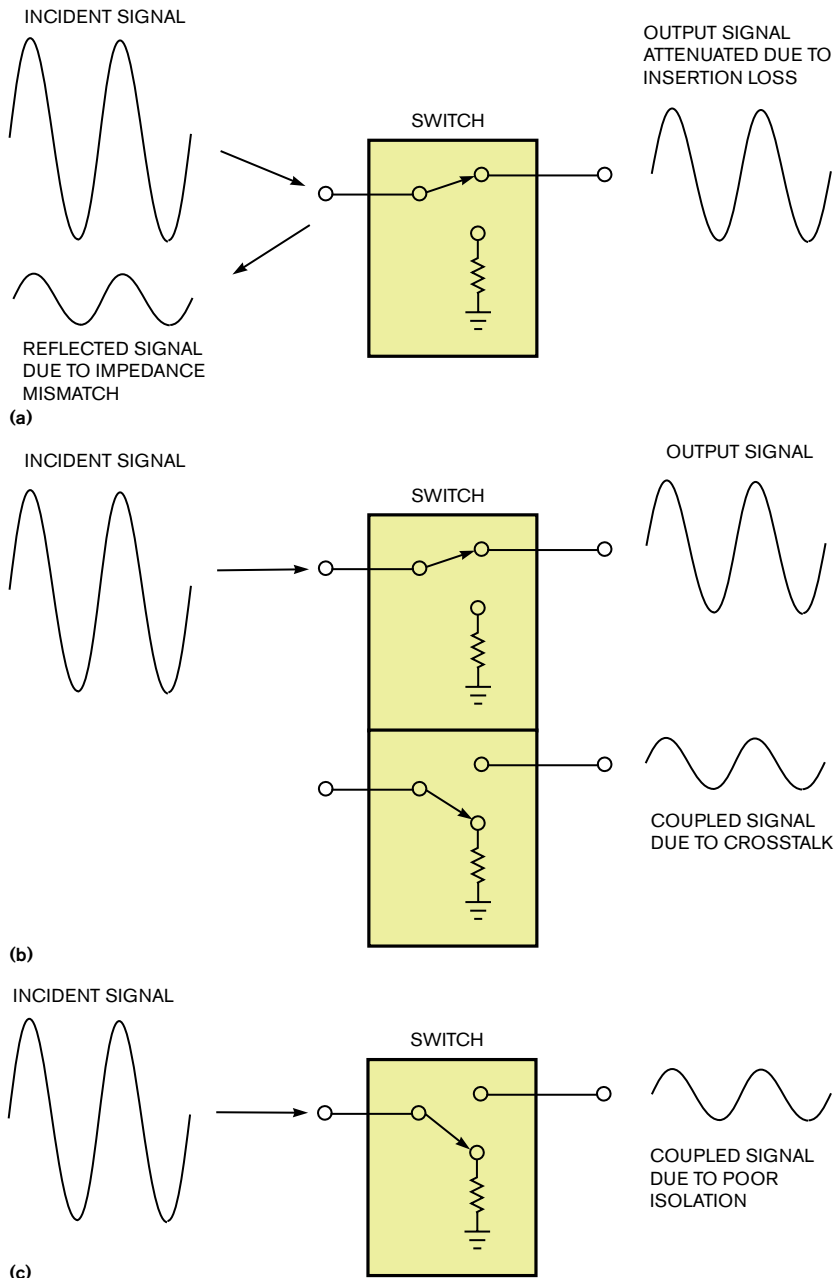


Figure 1 Lumped-element models typically represent transmission lines, with successive infinitesimal segments, interconnected by an ideal transmission line, having series resistance R, series inductance L, shunt conductance G, and shunt capacitance C, from which you can calculate characteristic impedance. Your switch should offer the same characteristic impedance.



**Figure 2** A switch can be subject to various deleterious effects. An impedance mismatch can result in input reflections, and the switch's insertion loss attenuates the output signal (a). In addition, an active switch can couple a signal to an adjacent inactive switch (b), and an open switch can couple a signal from its input to its output (c).

ple, they require no dc-blocking capacitors and come in small packages, such as the ADG919's 3×3-mm QFN. They also operate on supply voltages of 1.65 to 2.75V, and they consume less than 1  $\mu$ A of current. In addition, the devices accept TTL (transistor-transistor-logic) inputs, simplifying their integration with other system components. At 1 GHz, in-

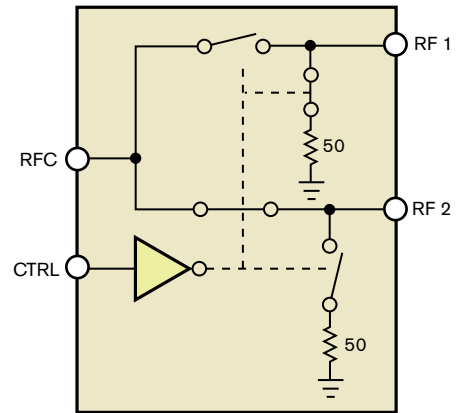
sertion loss is 0.8 dB and isolation is 43 dB. As for power-handling capability, the 1-dB compression point is 17 dBm. The devices successfully pass 1-kV HBM (human-body-model) ESD (electrostatic-discharge) tests on RF pins and 2-kV HBM ESD tests on non-RF pins. The switches are available in absorptive and reflective versions.

Goggin and Quill note that bulk-CMOS switches have lower bandwidth and maximum switched-RF power than do other switches, but, for applications whose requirements fall within bulk-CMOS limitations, the bulk-CMOS devices offer cost advantages. They also note that each device exhibits a footprint as small as 9 mm<sup>2</sup> in a CSP (chip-scale package) and can integrate driver circuitry, thereby eliminating the need for separate ICs.

### MEMS AND SOS DEVICES

If your application requires performance levels that lie beyond what bulk-CMOS devices can provide, you might consider a MEMS switch. Omron's 2SMES-01, for example, operates to 10 GHz, offering 30-dB isolation and 1-dB insertion loss (Figure 4). It offers maximum power consumption of 10  $\mu$ W, which, according to Donna Sandfox, product manager at Omron Electronic Components LLC, is about one ten-thousandth that of an equivalent electromagnetic relay.

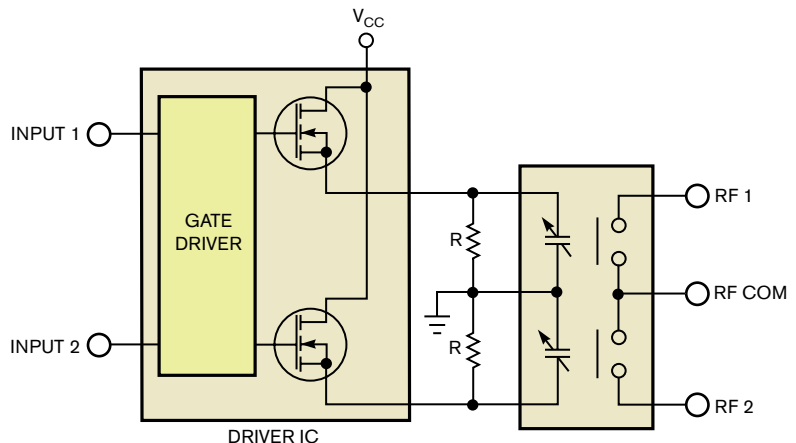
The device targets high-throughput ATE (automated-test-equipment) applications. An electrostatic-drive system powers the device, which performs 100 million operations switching a resistive load at 0.5 mA and 0.5V dc. Sandfox says the company has tested the device over 1 billion cycles. Each switch con-



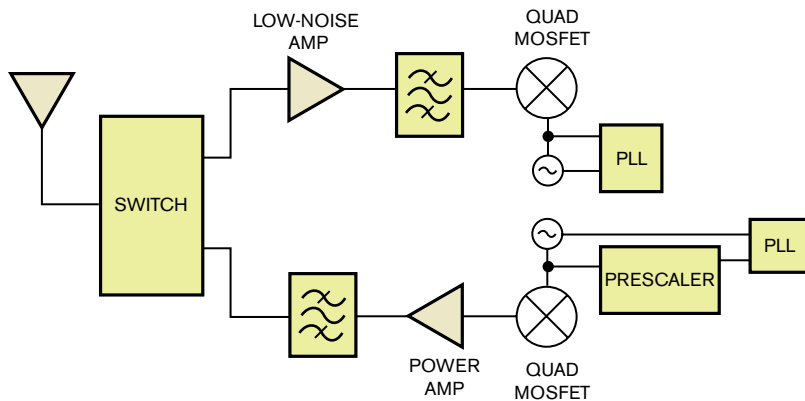
**Figure 3** The Analog Devices SPDT ADG918 absorptive switch has 50 $\Omega$ -terminated shunt resistors to ground, minimizing reflections back to the RF source. It is available in a 3 $\times$ 3-mm chip-scale package.

sists of two normally open SPST (single-pole/single-throw) silicon switches in a 5.2 $\times$ 3.0 $\times$ 1.8-mm housing offering SPDT or DPST (double-pole/single-throw) normally open operation.

Peregrine Semiconductor addresses the RF-switch market with its Ultra-CMOS SOS (silicon-on-sapphire) technology, which integrates ultrathin-silicon-CMOS circuitry on an insulating dielectric sapphire substrate. Peregrine also targets ATE and other applications, including digital TV, cable and satellite set-top boxes, game consoles, and cellular communications. For RF trans-



**Figure 4** An electrostatic-drive system powers Omron's 2SMES-01, which operates to 10 GHz, offering 30-dB isolation and 1-dB insertion loss. It performs 100 million operations switching a resistive load.



**Figure 5** For RF-transceiver applications, Peregrine Semiconductor complements its switches with UltraCMOS quad MOSFETs, PLLs, and prescalers.

ceivers, the company complements its switches with UltraCMOS quad MOSFETs, PLLs, and prescalers (**Figure 5**), enabling Peregrine parts to make up a substantial portion of the RF-signal chain. Rodd Novak, vice president of sales, marketing, and business development, says that the handset market offers high-volume opportunities, with the company's nine-throw switches going into pentaband phones.

For ATE applications, Peregrine offers the PE42552 absorptive SPDT device, which operates to 7.5 GHz with a 1-dB compression point of 34.5 dBm. Insertion loss is 0.65 dB at 3 GHz. Also for ATE applications, the company complements the PE42552 switch with the PE43703 7-bit digital step attenuator.

Mark Schrepferman, director of sales and marketing for communications and industrial markets at Peregrine, says that Peregrine has learned a lot about how to serve the test-equipment market from looking at its own test needs. Christian Steele, product-development section manager at Peregrine, recounts one major problem. Big-box ATE systems, he says, often include one or two sources and one or two receivers and rely on electromechanical switches to route signals among the available instruments and the multiport devices under test. "A lot of those mechanical switches have a reliability of very few throws—often less than 2 million," he explains. "At the volumes in which we are shipping our handset switches, we would be replacing very expensive mechanical switches in

less than a month." The cover story of the October issue of *EDN's* sister publication *Test & Measurement World* will describe how Peregrine engineers perform engineering characterization and production test of SOS devices.

Schrepferman says he has learned a lot from Steele and colleagues involved in test at Peregrine and has put the infor-

mation to good use. He notes that, even in the down economy, the company has seen "a tremendous number of design wins" in the test-equipment market.

As RF-switch technology advances, there is unlikely to be a clear-cut winner serving all applications, and Peregrine is evaluating multiple technologies. At Peregrine, there is one restriction. Ron Reedy, co-founder and chief technology officer, says that he put one edict in place when he founded the company: "Don't get in front of the CMOS steamroller." If you can implement something in bulk silicon CMOS, which he calls mankind's greatest volume accomplishment by any standard, then that's how you should implement it.

Reedy says that Peregrine is investigating MEMS, noting that, "from a performance point of view, it's pretty hard to beat metal contact." It's counterproductive, however, to put a high-performance switch on a lossy substrate, and work is under way to see whether MEMS belong on sapphire. "We would not say there is a single technical solution that covers all applications," he adds. **EDN**

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