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A Review of RF/Microwave Switching Technologies

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This tutorial article provides an overview of switching technologies commonly used at high frequencies

One of the most common functions in all electronic circuitry is switching. At high frequencies, many issues relating to performance of any circuit also apply to switches. The most important are:

- Loss versus frequency (bandwidth)
- VSWR versus frequency (mismatch)
- On-off isolation (feed-through)
- Isolation to other circuitry (crosstalk)
- Power handling
- Switching speed
- Operating lifetime (reliability, MTTF)

Other basic parameters that are important for specific applications include physical size, operating voltage, power consumption and rated temperature range. In instrumentation applications, excellent repeatability (consistency of performance from one operation to the next) is required.

Switching has a wide range of uses. The remainder of this article looks at individual switches by technology, and at switch assembly products.

1. Electromechanical Switches

Electromechanical switches are most often used for high power, or where the lowest possible loss is required. Both of these requirements are best met with the physical connection of metal-to-metal contacts.

Conventional relays

At frequencies below 500 MHz, it is often possible to use general-purpose relays that are primarily designed for control of AC/DC power. Certain manufacturing methods unintentionally result in reasonably low capacitance between open contacts, and low inductance in the internal connection. Although limited to the range from low frequencies through VHF, this part of the spectrum includes many communications and IF applications.

RF optimized relays

I define this group as an extension to the above—manufactured like general-purpose relays, but with improvements in the internal construction that further enhance RF performance. Most relays in this group are characterized up to 1 GHz, and offer a price/performance choice that fits many applications.

Microwave relays

The above relays types have limitations on some aspects of performance, usually *off* isolation and *crosstalk*. To handle switching at higher frequencies, and with higher performance, specially-designed relays are a typical solution. This family of relays might be better described as switches with electrical actuators, since they often bear little resemblance to general-purpose relays.

To maintain low VSWR, these devices are designed with short signal paths and a physical structure that mimics either stripline or coaxial line. High isolation is obtained by grounding the signal path in the *off* position, perhaps augmented by actuation movement that increases the distance between disconnected contacts, lowering the capacitance. Crosstalk is reduced with shielding between signal paths and ports, often cast or machined into the switch housing.

Manual switches

It is common to have versions of the above-described relays that are manually-operated, for test bench use or for applications that only require occasional changeover between circuits, e.g., to connect a backup radio or antenna at a communication facility.

2. Solid State Switches

Solid state switches are used when switching speed and reliability are key performance issues. They also are low cost and have small physical size. The combination of low power consumption and small size generally simplifies the design of the surrounding circuitry.

Forward-biased diodes

For circuit-level RF switching, a diode biased to full conduction is quite effective. Various technologies—silicon, “hot carrier,” GaAs and others—offer various options for loss, frequency range, and compatibility with the rest of the circuitry. A forward-biased diode has low loss and can be configured for high *off* isolation and low crosstalk levels. Since the control voltage shares the signal path, DC isolation is required for the signal and RF isolation is required for the control voltage.

PIN diodes

Entire books have been written about the PIN diode! This structure has been developed specifically for RF/microwave use, with the special property of varying resistance between the full *on* and full *off* states, controlled by the current flow. They have low resistance in the *on* state, making them one of the few solid-state choices for switching RF power.

To use the variable resistance feature, driving circuitry is required, which increases overall system complexity. Like the simple p-n junction diodes above, PINs also require DC isolation of the signal path and RF isolation of the control circuitry.

When used for high power, PIN diodes require high voltage to minimize the effects of the voltage swing of the signal. For example, 100 watts of power has a peak-to-peak voltage of 200 V in a 50 ohm system. The control voltage must exceed this value by amount sufficient to prevent the signal voltage from controlling the resistance of the diode and creating distortion products.

FET Switches

First marketed as “analog switches,” field-effect transistors (FETs) are effective small-signal switches that are highly flexible in their application. The FET structure provides significant RF isolation between the control voltage at the gate and the signal path between the source and drain. Switching speeds in the single-digit nanosecond range can be obtained, which rivals many low-cost diode switch options. A FET switch may also be designed to have a well-controlled variable resistance between the *on* and *off* states.

The primary drawbacks are relatively high *on* resistance and limited signal handing capability. The latter can result in interaction of the signal and control, as noted above for high power switching in PIN diodes. In the case of the FET, signals levels should not modulate the gate-source control voltage.

Integrated Circuits

ICs using CMOS, GaAs and other semiconductor technologies allow incorporation of switches into the IC’s other functionality. An IC can also have multiple switches in various configurations, greatly reducing the required p.c. board space.

MEMS Switches

I will include MEMS (micro electromechanical systems) switches in the solid-state category, since they are fabricated and used in this manner. They are actually mechanical switches constructed at the chip level, using electrostatic forces to move actuators in and out of contact. This technology combines the low loss of a mechanical contact with the small size of chip-level fabrication. Usage of this relatively new technology is increasing, although we still need to gain experience in selecting the best applications. Also, long-term real-world data on reliability and performance degradation is still being acquired.

3. Switch Assemblies

The final group we’ll look at are combinations of switches assembled and packaged as a finished product. These switches support system-level applications in communications, instrumentation, and wherever else signal-routing capability is needed.

Rather than discuss the technologies internal to the instruments, we’ll highlight the key system level requirements.

Test & Measurement

Automated test systems are the biggest application area for box-level switch assemblies. Key performance issues are low loss, long lifetime, and consistent performance over that lifetime. Additional important issues are the control method and physical form factor. Many test systems use standardized bus structures such as VXI, PXI or require standard interfaces like IEEE/GPIB, and more recently IP-based Ethernet control.

Control/routing applications

Switch assemblies for communications will be specified according to the application. For example, high intercept point will be important for all receiving systems; fast switching is required for SIGINT systems. Low crosstalk and high isolation are essential, since most communications involves signal ranges exceeding 100 dB from weakest to strongest. The required bandwidth will vary from <100 MHz for video, baseband and HF/VHF, up to many GHz.