Application Note
AN18

RF Switch Performance Advantages of UltraCMOS™ Technology over GaAs Technology

Introduction

In RF systems, switches are as common as amplifiers, mixers, and PLLs. While many technologies yield good active RF devices, few yield good RF switches. Superior switches are available in Peregrine's UltraCMOS™ process technology.

The dominant technology in the RF switch market has been GaAs. GaAs offers good linearity and isolation with low ON resistance and low OFF capacitance. However, GaAs has disadvantages. Most electronic systems use positive supplies, but most GaAs RF switches are N-channel depletion-mode FETs which require negative gate voltage to turn off. Driving GaAs switches also frequently requires extra interface components. Finally, GaAs has very limited capability to integrate other functions such as logic control and memory.

The UltraCMOS process technology is a patented silicon-on-sapphire (SOS) technology that uses CMOS circuitry on an insulating dielectric sapphire substrate. UltraCMOS technology matches the RF performance of GaAs with a single supply and has on-chip digital logic. Simpler controls reduce part count and total design cost. It also provides additional advantages including very high ESD protection (up to 2000V HBM and more). All this, and UltraCMOS switches are still price-competitive.

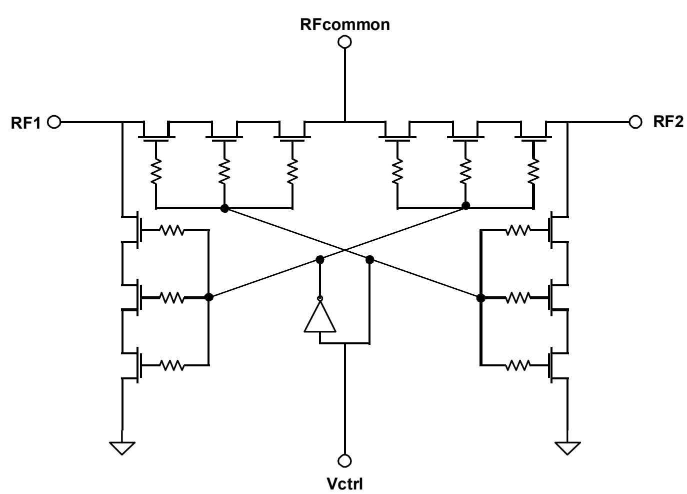
GaAs Switches

Figure 1 is a model of a typical RF switch, including GaAs switches. RF switches are arrays of transistors acting like voltage-controlled resistors. Isolation to deselected ports is achieved by turning off series transistors and grounding shunt transistors. Multiple transistors between common nodes increase power handling and improve linearity. GaAs switches most often use N-channel depletion-mode FETs. Pinch-off

Summary:

- Excellent wideband frequency linearity – ideal for RF and CATV systems
- Outstanding isolation and insertion loss
- Simplified single-pin CMOS control
- Reduced part count - no coupling capacitors on RF ports
- Low power operation at 3V
- Unpowered operation for CATV
- High IP3 for WCDMA transmitters

Figure 1. Typical RF Switch Structure



typically occurs when gate voltage is –2 to –3 V so the gate is normally biased at 0 V.

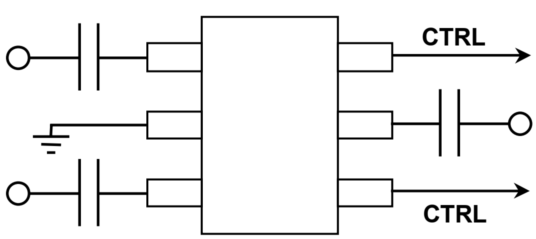
A problem with GaAs switches occurs in high power operation. High RF power can modulate the gate voltage, which varies channel resistance and generates distortion products. Increasing DC voltage on the gate can reduce this effect, but even modest RF power may require gate voltage of 1 to 2 V to turn the FET on and -3 V and sometimes –5 to –8 V to turn the FET off. Performance for low voltage systems is therefore often significantly degraded.

Another problem is that GaAs switches require coupling capacitors. While inexpensive, capacitors are not free and inventory, board space, and placement may cost even more. External capacitors constrain the minimum operating frequency. Capacitors also have insertion loss, and while usually minimal, in some systems even 0.1 dB is significant.

Some manufacturers instead integrate coupling capacitors in their GaAs switches. This eliminates external components, but monolithic capacitors are typically lower Q than discrete capacitors. Values greater than 10 pF can increase die size and cost. These switches are not suitable for low frequency or wideband applications.

Positive logic control is another problem for GaAs because implementing complementary logic in GaAs consumes significant current. One way to get around this is to float the die relative to DC ground.

Figure 2. Typical RF Switch Structure



Consider the typical SPDT in Figure 2. Every RF interface is capacitor-coupled. Now tie the ground terminal positive and the negative terminal to ground - the switch will operate with positive voltage. By floating the device, positive bias pulls the channels up to a voltage close to the control voltage. This creates a negative bias when the gate is grounded. Other tricks include pulling the channels up to supply voltage externally or using an internal resistive divider to pull the channels up to one-half of supply.

Another way GaAs switch manufacturers try to get around positive control logic problems is by mixing processes. For example, in packaged multi-throw switches they add a CMOS die. The auxiliary die provides complementary and decoded control lines and level-shifting, but both positive and negative supplies are still required as well as a larger package. The second die increases cost and reduces reliability.

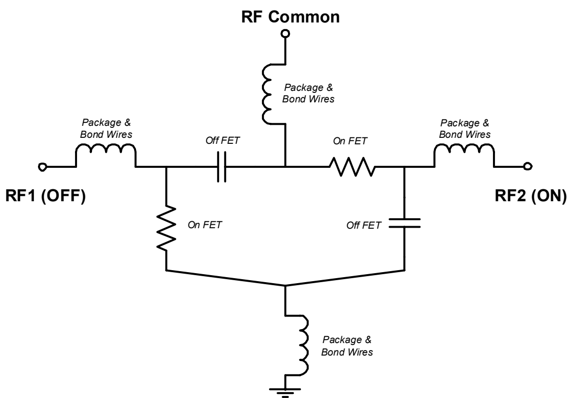
Integrated logic is yet another problem for GaAs switches. N-channel FET GaAs switches with integrated logic require resistors and a lot of current. Complementary device GaAs switches with integrated logic are unique, expensive, and still draw current.

Peregrine UltraCMOS™ Technology

Peregrine RF switches are fabricated using the patented UltraCMOS technology process. This process provides the RF performance of GaAs, including similar insertion loss and isolation, while offering additional capabilities GaAs technology lacks.

Figure 3 is a small signal model of an SPDT switch. Like GaAs, UltraCMOS-based RF switches are FETs that act as voltage-controlled resistors. ON-series resistance (R_{ON}) and the OFF-equivalent capacitance (C_{OFF}) is similar to GaAs. In 0.5-micron UltraCMOS technology the R_{ON} x C_{OFF} product is as low as 800 Ω -fF, and R_{ON} and C_{OFF} figures-of-merit improve as process geometry shrinks.

Figure 3. Small-signal Model of SPDT RF Switch



Low power switches (P1dB up to +27 dBm) use transistors with thresholds of 0.8 volts. Low-voltage CMOS logic drive them directly. In higher power switches (P1dB up to +30dBm), a 3-volt control span is insufficient for signal swing. Once again, UltraCMOS technology has a solution because any CMOS function is easily integrated.

Adding a negative voltage generator (NVG) increases operating range of each FET from two times threshold voltage to two times supply voltage. This also permits use of high-performance 0 V_{TH} transistors. Although the NVG introduces a noise spur, it is extremely low (about -127dBm), in part due to the high isolation of the sapphire substrate. Note: an integrated NVG is *inconceivable* in GaAs.

Figure 4. UltraCMOS-based SPDT RF Switch Functional Model

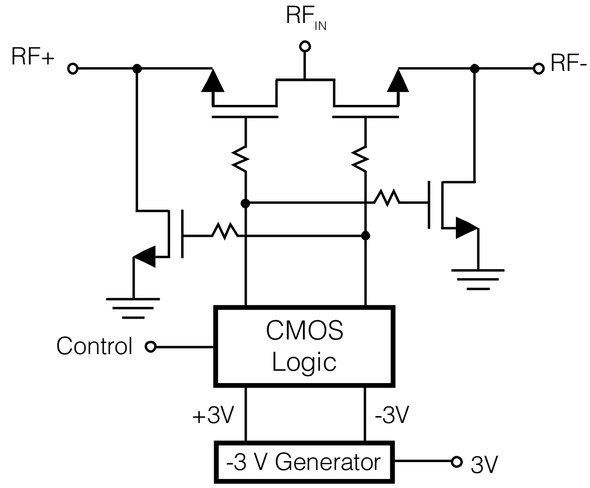


Figure 4 shows the block diagram of a high-power UltraCMOS RF switch, including integrated NVG and logic, providing true single-wire control.

Another tremendous advantage of UltraCMOS technology is integrated control logic. A GaAs SPDT typically requires two dedicated pins from the controller. GaAs switches often also require significant control currents and external buffering. Peregrine's switches always provide CMOS-compatible control.

This simplified control is even more beneficial in multi-throw switches. A GaAs SP6T requires 10 control pins. An UltraCMOS-based SP6T can be implemented with 3 decoded input lines or even a 3-pin serial interface. The results are fewer microprocessor pins, fewer package pins, elimination of support circuitry, and simpler PCB routing.

Summary

A design with GaAs RF switches requires external circuitry and costly and complex level conversion for positive logic control. A design with Peregrine Semiconductor's RF switches is less costly and complex because UltraCMOS-based switches require no coupling capacitors, interface directly with positive logic control, achieve high IP3 for 3V systems, and integrate decoding, serial, and/or parallel interfaces.

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