AN18: Application Note

Performance Benefits of UTSi CMOS RF Switch Technology Compared to GaAs Based RF Switches

Features

- Excellent wideband frequency linearity performance – ideal for RF and CATV systems
- Outstanding isolation and insertion loss characteristics
- Single-pin CMOS control simplifies control logic support
- Eliminate capacitors on RF ports
- Integrated charge pump on high power handling switches offers high IP3 for 3-volt systems
- Low power operation @ 3V:
  PE4239 – 250 nA, 27 dBm P1dB
  PE4237 – 33 µA, 32 dBm P1dB

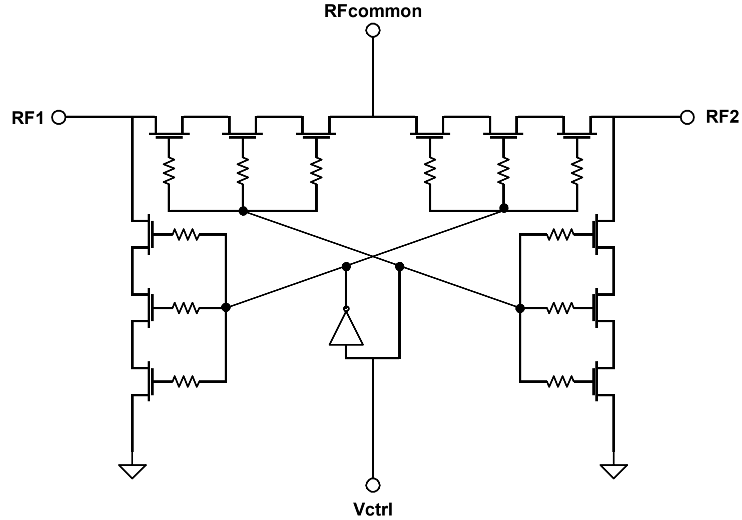
Introduction

Switches in RF systems are as common as amplifiers, mixers, and PLLs. While there are many processes that can be used to implement amplifier, mixer, and PLL functions, only a few processes support good RF switches. The RF switch market has typically been dominated by GaAs processes. GaAs has dominated the switch market because it offered low On resistances, low Off capacitances, and high linearity.

Now a new process is available, Peregrine's Ultra-Thin Silicon-on-Sapphire (UTSi®) CMOS process, which matches these positive GaAs attributes and additionally offers advanced integration capabilities. Monolithic GaAs RF switches are available from many vendors. Almost all use similar based N-channel depletion mode FET transistors. This transistor type conducts with zero gate voltage and turns off with a negative gate voltage. Most electronic systems use positive supplies and require extra interface components to drive GaAs RF switches.

Peregrine Semiconductor offers a unique family of high performance UTSi CMOS RF switches. Peregrine RF switches inherently operate with a positive supply, positive control, and include on-chip digital logic for single wire operation. Although price competitive part vs. part, UTSi RF switches offer a simpler control interface that further reduces part count and function cost.

Figure 1. Typical RF Switch Structure



GaAs Transistor Characteristics

An apples-to-apples comparison requires an understanding of the two underlying processes; GaAs and UTSi. Monolithic RF switches are made of arrays of similar transistors that act together as voltage controlled resistors. Series devices open and close RF paths and node-to-ground devices shunt deselected ports for increased isolation. Shown in Figure 1 is a typical functional model of an RF switch. Multiple transistors in series increase the power handling capability and improve the linearity of both series and shunt groups. The cross-connected gate connections demonstrate another important switch requirement, complementary control. Switch operation simultaneously requires both high and low level control voltages.

N-channel depletion mode GaAs transistors are conductive with a zero-volt gate-channel bias. Pinchoff, the voltage where the channel becomes high impedance, typically occurs between a –2 to –3 volt gate-channel bias and will vary according to the specific GaAs process. The RF input power places additional voltage on the channel and can modulate the instantaneous gate-to-channel voltage. When this happens, the channel resistance varies and the switch generates distortion products. Higher control voltages can reduce this effect and for even modest power levels the preferred gate voltages levels may be one to two volts above ground for ON paths and –5 to –8 volts for OFF paths. GaAs switch data sheets often show this explicitly with graphs for various control voltages and the low voltage performance may be significantly less than that purported on the first page marketing summary.

Putting these pieces together we can assemble the native drive requirements for a typical GaAs RF switch.

- ON transistors require 0 volts gate-channel, and sometimes higher
- OFF transistors require –3 volts gate-channel, and sometimes –5 to –8 volts
- Switches with both series and shunt elements require complementary control

Some manufacturers integrate the coupling capacitors on the die. This eliminates the nuisance of external components but comes with some limitations. On-die capacitors typically have more loss, i.e. lower Q. Large values (more than 10 pF) can increase the die size and therefore cost. These RF switches will work at specific wireless bands but are not suitable for low frequency or wideband applications.

GaAs Interface Methods

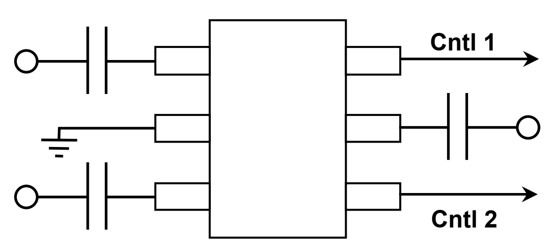
GaAs RF switches are, by themselves, inherently incompatible with positive-logic control. This is because GaAs processes do not offer complimentary devices and would consume current to create the complimentary logic function.

Three common recipes can give the illusion of positive control with varying degrees of cost and inconvenience.

Capacitive Coupling

Capacitors at every RF interface float the die relative to DC ground. If the switch's ground terminal ties to a positive voltage, and the negative terminal connects to system ground, it appears that the part is now operating with the more desirable positive voltage control. Figure 2 shows a typical SPDT application found in many datasheets. By floating the entire switch structure, the positive bias pulls the channels up to a voltage close to the positive control voltage. This in turn places a negative bias on the devices whose gate is held at ground. Other tricks are sometimes used, e.g. having the user pull the channels up to the supply voltage externally or by using an internal resistive divider to pull the channels up to one-half of the supply.

Figure 2. GaAs RF Switch



External capacitors set the minimum operating frequency according to their value. While capacitors are inexpensive, they are not free. Often ignored are the inventory, board space, and placement costs that may even exceed the cost of the capacitors alone. Similarly, capacitors usually have low insertion loss, but it is not zero. A 2X capacitor loss adds to the total insertion loss and may become important when comparing devices that differ by only tenths of a dB.

<u>MCM</u>

Some vendors add a second CMOS die inside the switch package for multi-throw switches. This auxiliary die performs level shifting and generates the needed complementary and decoded control lines. If desired, the mixed process hybrid also allows bipolar supply operation; positive for the logic interface and negative for the GaAs circuits. In either case the second die reduces reliability, increases cost, and typically excludes smaller package styles. Subsequent paragraphs will show that the benefits of a two die CMOS/GaAs hybrid are naturally available in a single, monolithic UTSi die.

<u>Discrete Driver</u>

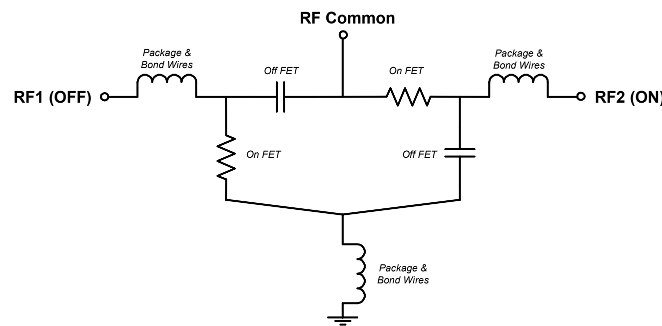
The most heroic interface method calls for external transistors, logic gates, and assorted passive components. Special cases such as nanosecond switching time, non-standard control levels, etc., may justify this effort and expense in rare circumstances.

Peregrine UTSi RF Switches

Peregrine RF switches are fabricated in a patented UTSi CMOS process that looks like conventional CMOS but has the RF performance of GaAs. As with GaAs, these UTSi RF switches are made with FETs that act as voltage controlled resistors. Their performance, as measured by the ON series resistance (Ron) and the OFF equivalent capacitance (Coff), is similar to GaAs. Side-by-side comparison of GaAs and UTSi RF switches show almost identical insertion loss for a given isolation. Figure 3 gives a small signal model of a SPDT switch. In the half-micron geometry of the UTSi process, the Ron value is ~ 5 ohms, and the Coff is ~ 0.5 pF. However, recent breakthroughs have driven the Ron-Coff product below 1000 Ohm-fF.

The Ron and Coff figures of merit for a switch improve as the process geometries shrink. Following the path of reduced feature sizes will further improve the UTSi switch performance.

Figure 3. Small-signal Model of SPDT RF Switch

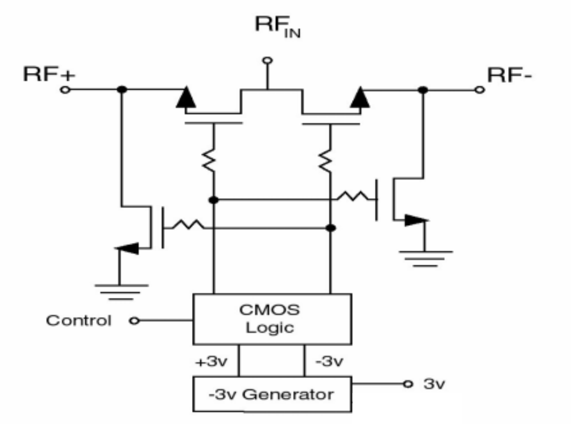


There are three different choices of threshold voltages in the UTSi process. Low-power RF switches (up to +27 dBm P1dB) use transistors with thresholds of 0.8 volts. Low-voltage CMOS logic will drive these transistors directly.

Higher power UTSi switches (up to +30 dBm P1dB) suffer the same shortcomings as GaAs, i.e. a 3-volt control span isn't really sufficient for the signal swings present. The UTSi process, however, allows a unique solution; an on-chip micro-power negative voltage generator. This increases the operating range of each FET from twice the threshold voltage to double the supply voltage, allowing the use of higher performance 0 Vth transistors.

While a charge pump is inconceivable in GaAs, any function normally found in CMOS is easily added to UTSi based components. Caution and conventional wisdom, though, say that a charge pump on the same die as an RF component may produce unacceptable spurious. But the high isolation of the sapphire substrate permits the successful same-die integration of these incompatible pieces. Figure 4 shows the block diagram of a high-power UTSi RF switch, including an integrated charge pump and integrated logic providing true single-wire control.

Figure 4. UTSi SPDT RF Switch Functional Model



The ability to integrate the control logic is a tremendous advantage for switches implemented in UTSi technology. A typical GaAs switch requires two control lines for an SPDT. This means two dedicated control pins from the microprocessor or controller. GaAs switches often require significant control currents which may require external buffering. Peregrine switches always provide CMOS compatible control inputs.

Peregrine's simplification of control interfaces is even more profound when you consider complex multi-throw switching requirements. For example, a SP5T in GaAs would require 10 control pins. A Peregrine UTSi SP5T could implement this control interface with 3 decoded input lines or even with a 3-pin serial interface. A simple 3-wire Serial Programming Interface (SPI) can in fact easily control an arbitrarily complex switching function as demonstrated by Peregrine's PE4460 4x6 RF Matrix Switch. The results are fewer microprocessor pins, fewer switch package pins, elimination of additional control support circuitry, and simpler PCB routing.

Summary

GaAs RF switches require negative voltages, capacitors, and/or additional logic and level conversion to operate with positive logic control. Peregrine Semiconductor's UTSi CMOS RF switches interface directly with positive logic control and offer the following associated advantages:

- No coupling capacitors
- Linear wideband operation
- Single-wire control for SPST and SPDT
- Integral decoding, on-chip serial or parallel interface
- Comparable RF insertion loss and isolation
- Integrated charge pump on high power handling switches offers high IP3 for 3 Volt systems
- Lowest total function cost

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