Enabling the State-of-the-Art in Automatic Test Equipment

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Abstract

One of the key building block components in any piece of high-end RF ATE solution is a single-pole, double-throw (SPDT), RF switch. These devices are used in many of the critical circuits and can have a profound impact on the overall performance of the ATE solution. The need for fast settling times, superior low frequency performance, high linearity, high electrostatic discharge (ESD) performance, and consistent IC quality is paramount for manufacturers of automatic test equipment (ATE). This paper examines how UltraCMOS™ CMOS-on-Sapphire technology solves these difficult performance challenges, and baselines an UltraCMOS RF switch against competing GaAs solutions.

INTRODUCTION

The challenges facing the RF test and measurement industry are classic chicken and egg problems. In order to make more efficient automatic test equipment (ATE), better RFICs are required, and, in order to make better RFICs, test equipment must be able to test the limits of the IC under development. As a result, top performing RFICs push the capabilities of the "state-of-the-art" test equipment used to develop them, in turn enabling the next generation of instrumentation that will be used to push the limits once again. This scenario invites a cooperative relationship between the top-performing IC design centers and industry-leading ATE manufacturers.

One of the key building block components in any piece of high-end RF ATE solution is a single-pole, double-throw (SPDT), RF switch. These devices are used in many of the critical circuits and can have a profound impact on the overall performance of the ATE solution. Among other important functions, switches are used to construct high performance digital step attenuators (DSAs; Figure 1), filter bank switching (Figure 2), and RF signal path selection within the ATE instrumentation.

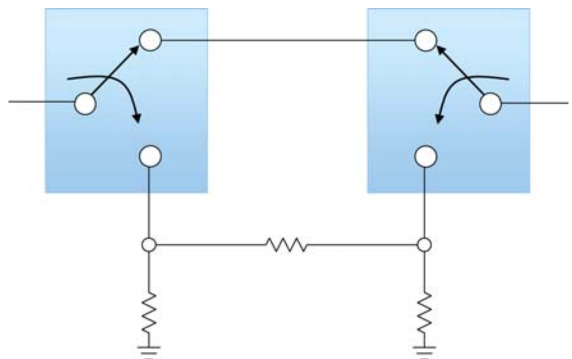

Figure 1 – Multiple switches are required to perform digital step attenuation (DSA) within ATE.

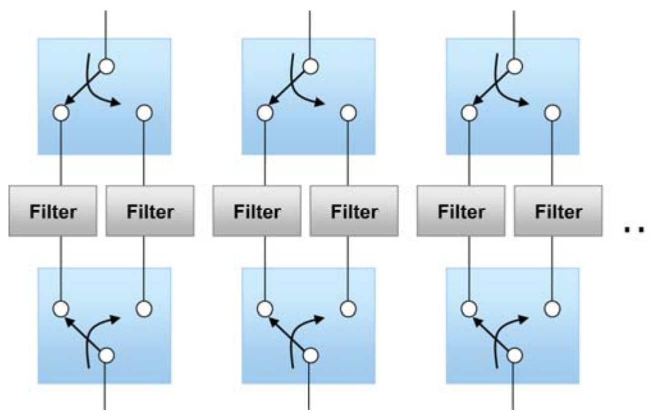

Figure 2 – Switches are used in filter bank switching in ATE.

The limitations of GaAs and SiGe in providing repeatable switching performance in these applications across a wide frequency range are well known. As a result, test equipment manufacturers have turned to highly-reliable CMOS semiconductor technology with expectations for higher performance. Their key expectations of silicon-based devices is that they will achieve fast settling times, superior low frequency performance, high linearity, high electrostatic discharge (ESD) performance, and consistent quality from chip to chip and lot to lot.

Switching Transients and Fast Settling Time

One of the most important aspects for ATE is fast settling time, because this allows the instrumentation to perform measurements faster, increasing throughput, usability and reducing manufacturing test costs. All of these improvements add up to measurable product advantages for ATE manufacturers who need to succeed in an extremely competitive environment. The well-known challenge here is that a typical GaAs-based switch demonstrates gate lag in settling time (see Figure 3), resulting in a phase and insertion loss drift.

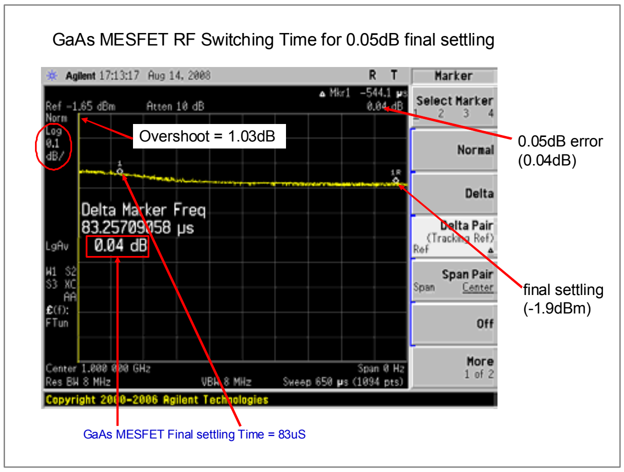

Figure 3 – This GaAs MESFET switch took 83 µs to achieve a 0.05dB final settling time, which is 63µs longer than ATE manufacturers require.

As a general rule, ATE manufacturers specify switch insertion loss to be within 0.05dBm in 20µs. Simply put, the faster the switch settles to within this 0.05dBm limit, the faster the ATE can report a measurement. Figure 3 shows a typical GaAs MESFET switch with a final settling time of 83µs. Note also that this GaAs switch also has a ~1dB overshoot after a switching event. This overshoot means that the transient power can be up to 26% higher than the final value, and if multiple switches are used, the transient power will be even higher. ATE engineers have had to compensate for these transients in their designs for many years.

In contrast, Figure 4 shows the performance of the PE42552 UltraCMOS™ switch from Peregrine Semiconductor. Note that this part settles to within 0.05dBm insertion loss within 13µs (faster than the ATE manufacturer specification of 20µs). And, it has no overshoot.

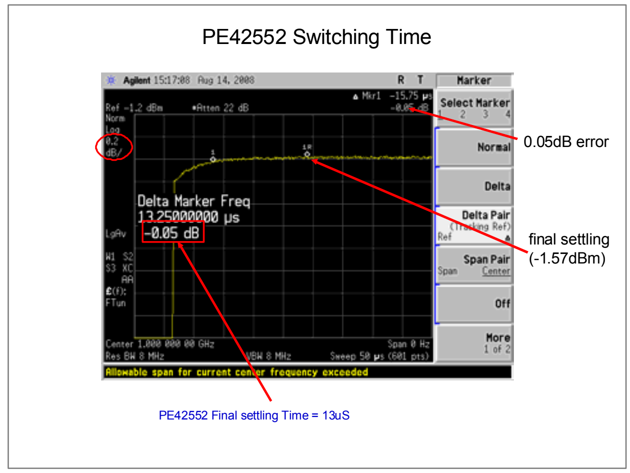

Figure 4 – A switch manufactured using silicon-on-sapphire UltraCMOS processing demonstrates a final settling time of 13µs with no overshoot.

In applications where switches are used to make attenuators (Figure 1) switching transient settling time delay (such as in Figure 3) can translate into errors in the attenuators or the switching function. In the DSA, for example, it is important to have accurate signal amplitude and phase, so that the rest of the instrument knows the correct signal level.

Unfortunately, the transient settling time in GaAs high-performance switches is unpredictable, which makes "designing and manufacturing around" them very challenging for ATE companies. Using an alternative device, such as a silicon switch, eliminates these design issues. To date, only UltraCMOS silicon-on-sapphire technology (SOS) has been able to support these stringent requirements in the switching function.

Low Frequency Performance and Linearity

Test and measurement equipment benefits from offering broadband performance, making it a more attractive investment to handle multiple communication protocols. As a result, the components inside must also be broadband. Many GaAs switches are specified to operate from DC and up. GaAs switches have a typical corner frequency of 100MHz; operating below this corner frequency significantly degrades linearity and introduces noise figure problems. Today, designers can use a single switch that offers high performance in the kilohertz range all the way up to 7500MHz. For example, the PE42552 SPDT switch operates from 9 kHz up to 7500MHz with high linearity performance across the frequency range.

Linearity at lower frequencies drives the ability of a switch to be used as a broadband component. Generally speaking, any non-linearity from components in the test and measurement equipment can cause intermodulation distortion (IMD), which can inhibit the equipment's ability to provide an accurate measurement. This is particularly challenging when the linearity of the IC in the ATE is as good as (or worse) than that of the device under test. As a result, ATE designers demand the very best linearity available. Figure 5 shows the PE42552 has significantly better performance than a GaAs MESFET switch at low frequency.

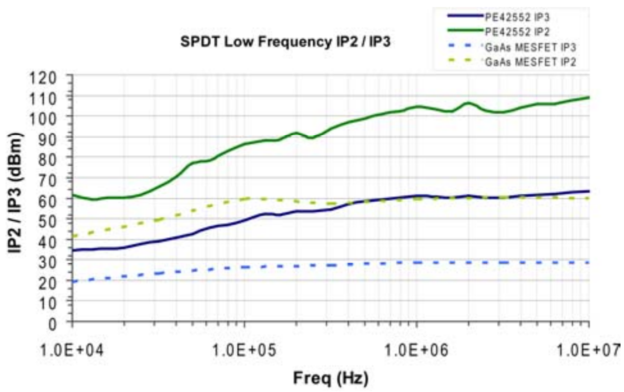

Figure 5 – A view of the linearity performance of an UltraCMOS switch as compared to that of a typical GaAs MESFET switch across the 10kHz to 10MHz low frequency range of interest.

ESD Protection

Typical GaAs MESFET switches have a Class 0 (<250V) or Class 1A (250V to 500V) HBM ESD rating and can be damaged by even small electrostatic discharge (ESD) events. This type of damage can be particularly challenging to detect, so it is best to avoid it. In response, ATE designers have traditionally added ESD protection to switches. Unfortunately, this external protection can limit the circuit performance (power and dynamic range) and degrade the instrument's overall performance. The integration advantages of silicon make it possible to include ESD protection devices within the silicon switch. UltraCMOS switches, for instance, provide class 1C performance on the RF pins (1000V to 2000V) HBM.

Consistent Performance

Precision is a key metric in ATE design. To achieve the required performance levels, ATE manufacturers need to minimize the variation in the performance of the switches they use. One inefficient way to do this is to screen each lot of switches, discarding the ones that are out of spec. Alternatively, MEMS switches can be used, but that technology is still challenged by reliability and repeatability issues as well. Readily available CMOS switches offer repeatable performance from lot to lot, due to the very nature of silicon processing. When they are confident in the consistency of switch performance, ATE manufacturers can eliminate the prescreening step and speed up production and delivery.

Besides the consistent broadband performance and linearity mentioned above, another important RF parameter for switches used in state-of-the art test equipment is consistent insertion loss performance. Insertion loss is important because, when there are many switches in the signal path, the loss of each switch becomes multiplied. The total loss, especially in higher power paths, results in higher power consumption. The insertion loss (and, therefore, noise figure) of switches can also limit the dynamic range in a receive path. Figure 6 shows that the typical insertion loss for an UltraCMOS broadband switch is <1dB at 7.5GHz, which is nearly 50% lower than comparable GaAs switches.

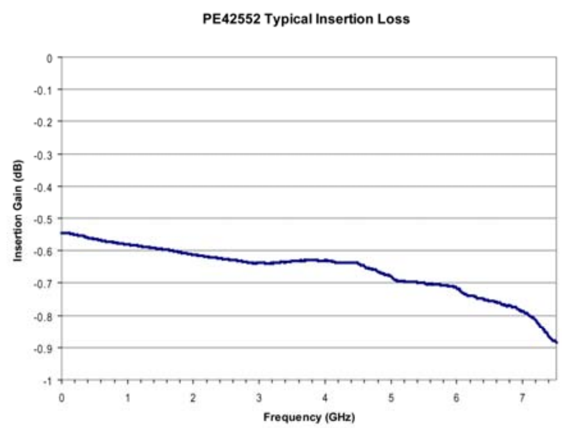

Figure 6 – The 42552 is a broadband switch with a typical insertion loss of <1dB at 7.5GHz which is nearly 50% lower than comparable GaAs switches.

Insertion loss performance can be closely tied to linearity. For instance, GaAs-based RF switches tend to demonstrate increased insertion loss and die size with linearity improvements. This is because the conventional circuits need multi-stacked FETs or multi-gate FETs and large gate width to achieve low distortion, which results in large parasitic off-capacitances with degraded insertion loss. In contrast, UltraCMOS technology is composed of a stack of FETs manufactured on a perfectly insulating sapphire substrate, providing the ability to pass high-power RF signals.

CMOS: A MATTER OF CONTROL

Having a CMOS interface on a device makes it much easier for any designer to use, and this is true for test and measurement as well. Normally a system's logic function is implemented in CMOS, so, if the switch is manufactured using a CMOS process, then the chip manufacturer can easily include logic on chip.

The PE42552 SPDT switch, for instance, was designed with integrated CMOS control logic that is driven by a single-pin, low-voltage CMOS control input. Another way to improve switch functionality is to enable a user-defined logic table. An UltraCMOS switch, for example, includes a logic-select pin that inverts logic polarity for back-to-back switching applications, effectively changing the logic definition of the control pin.

As test and measurement manufacturers gear up for Long-Term-Evolution (LTE) mobile phones, mobile WiMAX, and, perhaps, a converged version of the two, the performance of their test equipment will be stretched to the maximum. Fortunately, they can offer the broadband, repeatable, accurate performance that their customers are demanding because UltraCMOS technology was commercialized years ago, is in high-volume production, and parts are being custom tailored for the ATE marketplace. In the end, today’s RF test instrumentation must make extremely accurate and repeatable measurements, the good news is that test and measurement suppliers have access to the devices that will allow them to meet their targets.

[1] Baker, Ray. "CMOS-based Digital Step Attenuator Designs," Wireless Design & Development Magazine, May 2004. http://www.psemi.com/articles/2004/2004_ar_5.pdf