Keysight Technologies
FET Switch Speed and Settling Time

Application Note
Introduction

The traditional measure of digital switching – the speed of moving to 90% on or 90% off – is typically a strength of FET switches. With good driver circuits, MWTC switches have been shown to switch within 5 nS; with exceptional drivers they have shown switching time less than 1 nS.

Many instrument applications have a much more demanding specification, requiring that the switch settle to within 0.3, 0.1, or 0.01 dB of the final value. Unfortunately, the total settling time for GaAs FET switches can be significantly longer than one or two extra time constants. This effect has been seen in several manufacturer’s GaAs switches; although most data sheets do not reference settling time, we believe this problem is present throughout the industry.

This application note explains the occurrence, the reasons, and some of the possible solutions for this “slowtails” FET switch behavior.

Why does this occur?

A FET switch typically includes one series FET and 1-7 shunt FETs to achieve good isolation. Increasing Gate voltage allows electrons to pass through the channel, turning on the switch. When the voltage is raised, some electrons are trapped in the substrate, which pinches off small portions of the channel. The switch is not fully on until those electrons are freed, which can take several milliseconds for 0.01 dB settling.

This effect has been demonstrated in all FET processes – internal and external – that we have seen.

Switches will typically function with less than their rated positive voltage. Switching speed is reduced with reduced positive voltage, but 50 nS slow tail amplitude appears unaffected. We do not have data on slow-tail time constant.

Will this affect me?

Stacking multiple switches in series exacerbates the effect. If your instrument needs to settle within 0.1 dB, and you have five switches, each one needs to settle within 0.02 dB on average.

There is noticeable performance variation between wafers. If the breadboard works, but you would be disturbed if the tails were twice as strong or several times as long, you should certainly examine statistics and consider possible design changes before moving into Proto. For 741s, we have seen that the tails are responsible for between 0.1 and 0.3 dB extra insertion loss 50 nS immediately after turn-on (0 - 1 mS). 0.01 dB insertion loss is usually achieved after 4 ms. There is some variation in the different devices.

What if I need improved performance?

There are several useful techniques, which have different trade-offs. In particular:

1. Verify performance requirements
2. Forward-bias the gate during switching (obsolete)
3. Use light
4. Investigate different technologies

These trade-offs tend to be most effective at reducing the time constant for clearing the electron traps, which significantly helps the longer-time problem. They have not been tested against the “immediately after turn-on” slow-tails effect.
Verify performance requirements Slow tails immediately after turn-on (5 nS – 1 μS) range from 0.1 to 0.25 dB. They generally range from 0.002 to 0.01 after 4 mS. Multiple chips in series will add in dB. If your application requires better accuracy, then it is worth investigating possible mitigation strategies.

**Forward-bias the gate (obsolete)**

The traditional FET switches (TC727, TC728) allow direct access to the gate. At one point, putting a forward bias of between 0.7 and 2 V on the gate was shown to reduce slow tails by a factor of 3.

Recent process modifications via a low-temperature buffer have allowed us to achieve better switch performance. Those changes make the forward bias unnecessary.

The low-distortion switches (TC732, TC741, TC950) have their gate protected by a diode to prevent gate forward bias. This significantly reduces distortion at high RF power. It is thus no longer possible to use this technique. We have experimented with special designs which allow forward bias; since the process change above the two designs have equivalent performance, so we have obsoleted this methodology.

**Use light**

Shining light onto a bare die uses photons to dislodge the electrons from the electron traps. Sufficient light dramatically accelerates the slow tails, resulting in a 50x improvement in 0.01 dB settling time. We have not investigated the use of light to improve 50 nS performance.

A variety of manufacturing techniques have been used to allow light-accelerated switching. If modest improvement is sufficient, CT PGU has demonstrated a reflected-light technique on an integrated PC board using ceramic packages. If significant improvement is required, SS PGU has used a highpower LEDs mounted to shine directly on bare die on a Pele module. For higher frequency operation, MWTC has also demonstrated light-accelerated switching in gold-brick modules.

For more detailed information about these technique, please contact MWTC marketing. Using light to accelerate GaAs FET switching is a Keysight Technologies, Inc. patent (Dean Nicholson).

**Investigate different technologies**

Other technologies do not have the same problem with settling, although there are some trade-offs.

**Pin diode switches**

Another mainstream switching technology. As the on-off switching uses the same path as the RF, they cannot be used for switching low-frequency signals. 10 MHz switching is straightforward using pin diode switches; 1 MHz switching is possible with careful product selection and design.

**MEMS switches (developing technology)**

Micromechanical switches now have reliability up to 107 cycles along with acceptable low-frequency performance. Switching speed is ~1 ms.

**LAMPS switches (early technology)**

High-speed low-distortion switches using integrated lasers to switch. Reliability nears that of a FET switch. These are early in the advanced development phase.

MWTC makes pin diode switches, and has investigated other technologies.
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