Long-term transient radiation effects in high-speed signal switches implemented in 0.1 um E/D pHEMT process

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Abstract. The transient radiation effects in 0.1 μm E/D pHEMT high-speed signal switches have been investigated. It was shown that a signal switch transient recovery time caused by pulsed irradiation can exceed 100 ms due to a switch control driver's functional upset.

1 Introduction

Microwave signal switches implemented in GaAs pseudomorphic high-electron-mobility transistor (pHEMT) processes are widely used in modern radio-frequency and microwave transceivers integrated circuits (ICs) as well as in digital step attenuators (AT) and phase shifters (PS) functional blocks [1]. Passive switches are the most attractive for AT and PS design because of its wide frequency range, low insertion loss, high input power, and reasonable cost. These switches consist of the microwave analog core implemented on depletion-mode pHEMT (D-pHEMT), that commutate the microwave energy between the input and outputs, and digital control driver (see Figure 1) [2]. Until recently, the series-produced switch ICs have been implementing as hybrid IC and including the analog switching core and the control driver, made as a separate die, usually silicon, due to the unavailability of the enhancement-mode pHEMT (E-pHEMT) in the processes technological libraries. For example, MAPS010163 PS (Macom Tech.) is based on two dies – a microwave GaAs PS-core and a CMOS control driver [3].

This paper is focused on the transient radiation effects in E/D-pHEMT high-speed microwave switches with integrated control drivers. In accordance to [4], the radiation tolerance of serial switches to the pulsed irradiations is determined by a parametric upset due to an insertion loss transient response (α_{OPEN} increase) at dose rate values (P) of $P \sim 10^7 \ldots 10^8$ a.u./s. with α_{OPEN} recovery time not less than 100 μs.

In this work, functional upsets in fully integrated GaAs E/D-pHEMT switches with a recovery time of more than 100 ms have been identified.

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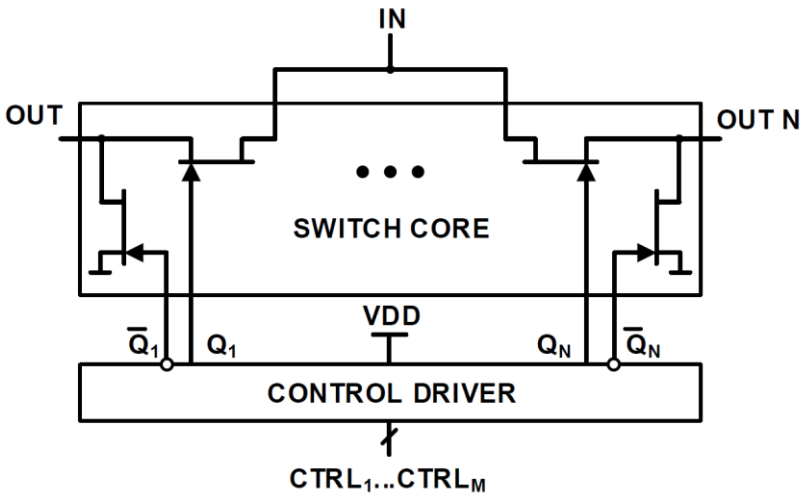

Fig. 1. Block diagram of a typical reflection-type switch.

2 Device under test and experimental results

A 0.1 μm E/D pHEMT single pole six throw (SP6T) signal switch ICs integrated with control driver have been tested. The microwave switch core is based on D-pHEMT. The control driver is based on E/D-pHEMT and consists of input and output digital buffers and a decoder. The SP6T signal switch operating frequency range is 0 - 4.1 GHz.

The radiation tests have been performed in JSC "SPELS" and MEPhI test center [5]. The irradiation have been done within the dose rate range from 10^7 a.u./s to 3 10^9 a.u./s, the ambient temperature range (T) of –60 ...+85 ℃, the supply voltage (V_{DD}) value of minus 5,15 V, and control voltage (V_{CTRL}) values of 4.5 V ("ON" state) and 0 V ("OFF" state).

A functional upset in the switch has been identified at a dose rate level of $1.5 \cdot 10^7$ a.u./s and higher, which represent in the turn-off of the channel. The dependence of the insertion loss ionizing response amplitude ($\Delta\alpha_{OPEN}$) on the dose rate value at the ambient temperature of 25 ℃ is shown in Figure 2, a. The dependence of $\Delta\alpha_{OPEN}$ on the dose rate level has two characteristic regions: monotonous growth of $\Delta\alpha_{OPEN}$ is observed before the functional failure, and the selected channel is turned off after the functional failure (increase of $\Delta\alpha_{OPEN}$ by 27 dB, this value is limited by the oscilloscope sensitivity threshold). The duration of the functional failure substantially depends on the dose rate level and the ambient temperature. At the dose rate level of $2.5 \cdot 10^9$ a.u./s and the ambient temperature of minus 60 ℃, the functional failure duration is 145 ms, which is shown in Figure 2, b.

In accordance to [4], the insertion loss long-term transient response is determined by the channel current modulation due to the charge accumulation and relaxation on deep levels in the buffer layer and semi-insulating substrate. This is confirmed by the temperature dependence of $\Delta\alpha_{OPEN}$ recovery time, which is a semi-logarithmic scale straight line (Arrhenius law), as presented in Figure 3 [6].

At T = –60 ℃ $\Delta\alpha_{OPEN}$ recovery time value is about 150 ms, which is two orders of magnitude higher than the same parameter at T is 25 ℃. The recovery time depends on V_{CTRL} has been obtained in the range from 3 V to 5 V (see Figure 3, b): given the V_{CTRL} is 3 V, recovery time is 150 ms, which is 3 orders of magnitude higher than the same parameter at V_{CTRL} is 5 V. The change of recovery time in the range of supply voltages V_{DD} (minus 4.85 V ... minus 5.15 V) is less than 2 times and does not exceed 210 ms at the value of minus 5.15 V and V_{CTRL} = 3 V (see Figure 3, c), which corresponds to the worst case.

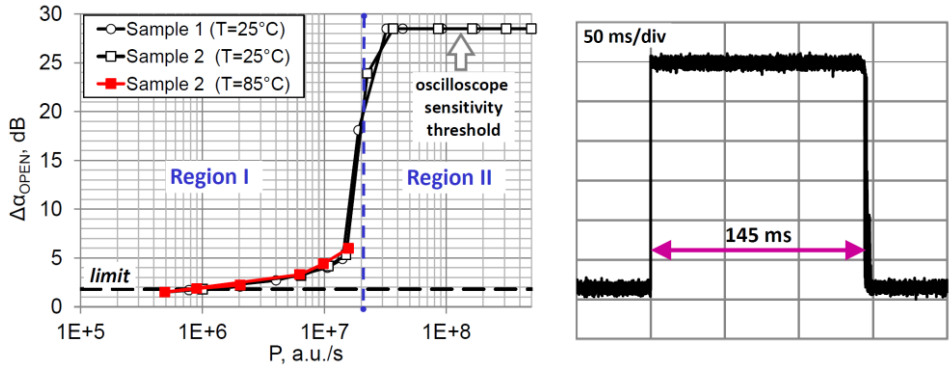

Fig. 2. Dependence of $\Delta\alpha_{OPEN}$ on the dose rate level P at T = 25 ℃ and V_{CTRL} = 4.5 V, V_{DD} = minus 5.15 V of the SP6T (a), waveform of the SP6T output signal's envelope power at $P = 2.5 \cdot 10^9$ a.u./s and T = –60 ℃, V_{CTRL} = 4.5 V, V_{DD} = minus 5.15 V (b).

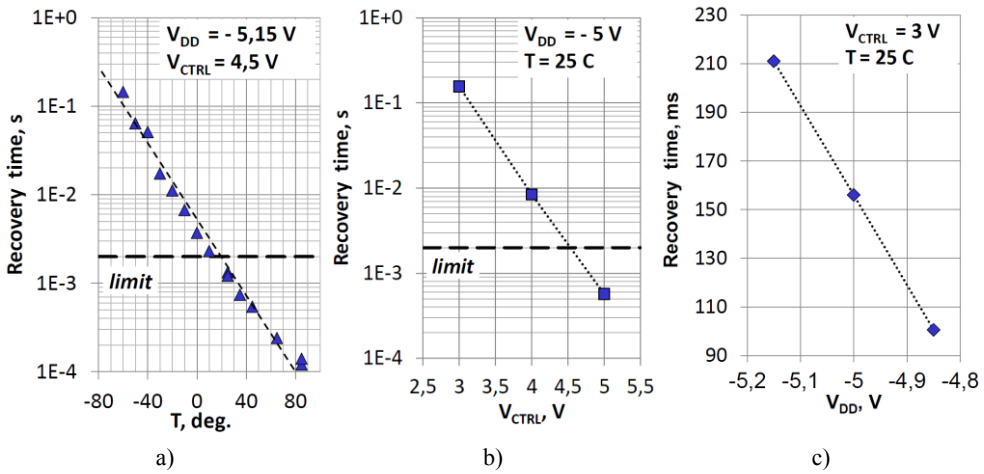

Fig. 3. Dependencies of SP6T' recovery time on ambient temperature at $P = 2 \cdot 10^9$ a.u./s (a), on control voltage V_{CTRL} (b) and supply voltage V_{DD} (c) at $P = 2.8 \cdot 10^9$ a.u./s.

3 Conclusion

The transient radiation effects in 0.1 μm E/D pHEMT high-speed signal switches with integrated control drivers have been investigated. It was shown that switches transient recovery time caused by pulsed irradiation can exceed 100 ms due to a switch control driver's functional upset. The temperature dependence of the insertion loss recovery time is represented by a straight line on a semi-logarithmic scale (Arrhenius law), that indicates that switch long-term transient response is determined by the channel current modulation due to the charge accumulation and relaxation on deep levels in the buffer layer and semi-insulating substrate.

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