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The influence of microwave pulse repetition frequency on the thermal burnout effect of a PIN diode limiting-amplifying system

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ABSTRACT

This paper analyzes the influence of the microwave pulse repetition frequency on the thermal burnout effect of a PIN diode limiting-amplifying system. Based on the study of the single-shot microwave pulse thermal burnout effect and by introducing a new assumption that the heat dissipation of the electric field energy and the nonequilibrium carrier energy during the microwave pulse intervals can be neglected, the theoretical thermal burnout model in our previous study is extended to be suitable for repetitive microwave pulses. The theoretical relationship among the pulse number, the pulse repetition frequency, the pulse width and the thermal burnout power threshold is obtained by theoretical derivation. Because the assumptions are introduced, the theoretical relationship requires that both the whole length of a repetitive microwave pulse and the pulse width in a cycle of a repetitive microwave pulse should be between 10 ns and 10 μs. The results obtained by the theoretical relationship are in good agreement with the simulation results obtained by our self-designed device-circuit joint simulator, which verifies the correctness of the theoretical analyses, modeling and derivation. By fitting at least two sets of simulation or experimental data, the theoretical relationship can be used to predict the thermal burnout power thresholds of PIN diode limiting-amplifying systems under microwave pulse injections with different pulse parameters. It can greatly reduce the simulation or experimental costs and could be helpful for the design of a radio frequency receiver.

1. Introduction

With the continuous increasing of the complexity of the electromagnetic environment, the threat of ambient interfering microwave pulses on electronic systems becomes more and more severe. External interfering microwave pulses can couple into a radio frequency (RF) receiver through the antenna and further damage the sensitive modules in the RF receiver [1].

Fig. 1 shows the typical structure of an RF receiver front end. The PIN diode limiting-amplifying system is a key system in an RF receiver front end which consists of a PIN diode limiter and a low noise amplifier (LNA) as shown in Fig. 1. The LNA can amplify the weak signal received by the antenna but it is vulnerable to high amplitude microwave pulses due to its required low input power [2]. Therefore, by using the conductivity modulation effect of PIN diodes, a PIN diode limiter is usually set as the front-stage module of the LNA to protect the LNA from being burnt out by high amplitude microwave pulses. However, both the core devices in a PIN diode limiter and an LNA are semiconductor devices. Compared with passive devices, semiconductor devices are more vulnerable to high power microwave pulses [1]. Thermal burnout phenomenon of the core semiconductor devices in a PIN diode limiting-amplifying system may still happen when high power microwave pulses are injected into the RF receiver [3].

As shown in Fig. 2, a typical repetitive microwave pulse is a narrow-band sinusoidal signal whose main parameters are the pulse power, the pulse width, the frequency and the pulse repetition frequency (PRF). The pulse power is in proportional to the square of the pulse amplitude. The pulse power, the pulse width and the PRF are directly related to the energy of the injected microwave pulses, which makes them the most significant parameters in analyzing the microwave pulse thermal burnout effect of the PIN diode limiting-amplifying system. Due to the limitation of the current manufacturing technology, it is usually a tradeoff between the pulse width and the pulse power for an actual microwave source. Microwave sources cannot generate a relative long pulse with relative high pulse power. Therefore, a single-shot microwave pulse may not be able to damage the semiconductor devices for its low energy. As shown in Fig. 2, using the pulse accumulative effect of repetitive microwave pulses, the maximum temperature in a

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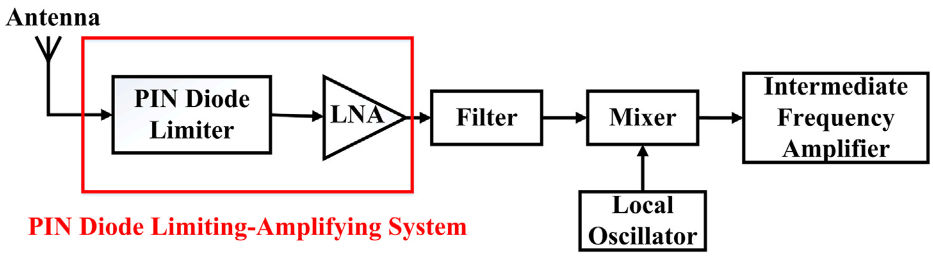

Fig. 1. Typical structure of an RF receiver front end.

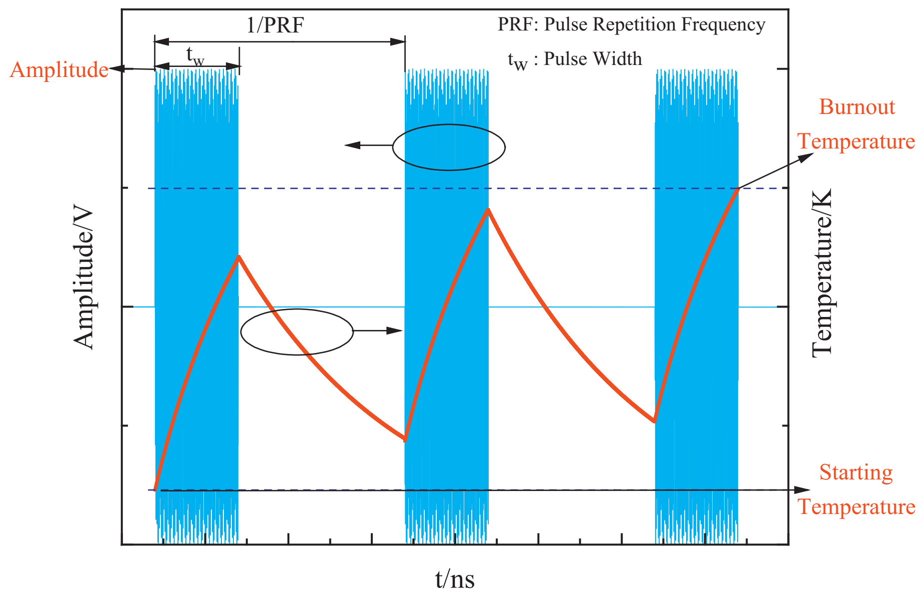

Fig. 2. Typical waveform of a repetitive microwave pulse and the corresponding maximum temperature variation curve in a semiconductor device.

semiconductor device will rise to the thermal burnout temperature after several cycles and the thermal burnout phenomenon will happen eventually. Thus, the repetitive microwave pulses may lower the thermal burnout power threshold, which makes them more threatening to semiconductor devices. As a result, it is of great significance to study the influence of the PRF on the thermal burnout effect of semiconductor devices.

There are already some studies about the microwave pulse thermal burnout effect of semiconductor devices and their corresponding circuits. Chen et al. studied the microwave pulse thermal burnout effects of PIN diodes and PIN diode limiters by analyzing the influence of microwave pulse width, frequency and PRF [4]. Hou et al. studied the influence of microwave pulse width on the thermal burnout effect of an LNA constructed by a SiGe heterojunction bipolar transistor with theoretical, simulation and experimental analyses [5]. Zhang et al. carried out experiments to study the thermal burnout effect of LNAs and observed the thermal burnout position in the damaged semiconductor devices by a scanning electron microscope [6]. Chen et al. studied the microwave pulse thermal burnout effects of several basic digital circuits with theoretical derivation and simulation verification [7,8]. However, the study on the microwave pulse thermal burnout effects of an RF system with multiple RF modules and semiconductor devices like a PIN diode limiting-amplifying system is quite limited. In our previous study [9], the microwave pulse thermal burnout effect of a PIN diode limiting-amplifying system consisting of a PIN diode limiter and an LNA constructed by a GaAs pseudomorphic high electron mobility transistor (PHEMT) is analyzed. By theoretical analyses based on the properties of the microwave pulses, the PIN diode and the PHEMT, the theoretical thermal burnout model for single-shot microwave pulses is established and the theoretical relationship between the microwave pulse width and the thermal burnout power threshold is obtained and further verified by simulation results.

In this paper, further study is carried out to analyze the influence of PRF on the thermal burnout effect of the above mentioned PIN diode limiting-amplifying system. Based on the results obtained by a single-shot microwave pulse [9], the theoretical thermal burnout model is extended to be suitable for repetitive microwave pulses and the relationship among the microwave pulse width, the PRF, the pulse number and the thermal burnout power threshold for a repetitive microwave pulse is obtained. Numerical simulations by our self-designed device-circuit joint simulator [4] are carried out to verify the correctness of the theoretical analyses, modeling and derivation. Our simulator is a combination of a circuit solver and a device solver by a time domain coupling algorithm. The circuit solver is similar to the PSpice software and the device solver can show the transient state in the semiconductor device by solving the semiconductor equations and the heat conduction equation based on the finite difference time-domain (FDTD) method. The correctness of our device-circuit joint simulator has been verified by comparing with the simulation results obtained by other commercial software (including Sentaurus and Medici) and experimental results in many cases [4,5].

The rest of this paper is organized as follows. In Section 2, the composition of the studied PIN diode limiting-amplifying system is introduced. In Section 3, the theoretical thermal burnout model for single-shot microwave pulses is extended to be suitable for repetitive microwave pulses and a theoretical relationship among the microwave pulse width, the PRF, the pulse number and the thermal burnout power threshold for a repetitive microwave pulse is obtained. In Section 4, numerical simulations by our self-designed device-circuit joint simulator are carried out to verify the correctness of the theoretical analyses,