# Design of narrow pulse light source driving circuit of laser fuze

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**Abstract:** Aiming at the miniaturization and high performance requirements of laser fuze, a novel driving circuit was designed to drive the pulse laser diode. The circuit used high-speed MOSFET as the switching element to generate a driving pulse with narrow pulse width, short rise time and large peak current for laser diode. A corresponding driving circuit model was established. The effects of supply voltage, energy storage capacitor and damping resistor on the performance of driving pulse were analyzed by simulation and experiment. A driving circuit with the size of 19 mm×10 mm was designed and the optimal circuit parameters were selected. The driving circuit provides a driving pulse with pulse width of 8.6 ns, rise time of 4 ns and peak current of 39 A. The design provides an effective improvement of detection performance of laser fuze.

**Key words:** laser fuze; laser diode; pulsed laser; driving circuit; narrow pulse

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# 激光引信窄脉冲光源驱动电路设计

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**摘　要:** 针对激光引信小型化和高性能的工作需求,设计了一种新型半导体激光器(LD)驱动电路。电路采用高速 MOSFET 作为开关器件,为激光器提供脉宽窄、上升时间短、峰值电流大的驱动脉冲。建立了相应的驱动电路模型,设计制作了尺寸为 19 mm×10 mm 的驱动电路,仿真和实验分析了供电电源、充电电容和阻尼电阻对驱动脉冲的影响。并根据仿真和实验结果选取最佳的电路参数,在此条件下驱动脉冲的脉宽为 8.6 ns、前沿上升时间为 4 ns、峰值电流为 39 A。该电路为激光引信探测性能的提高提供参考。

**关键词:** 激光引信; 半导体激光器; 脉冲激光; 驱动电路; 窄脉冲

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## 0 Introduction

Laser diode (LD) is widely used in the fields of industry, military and science, on account of its small size, high reliability and energy concentration. Laser fuze has the advantages of direction, precision and anti-interference ability compared with the traditional radio fuze and infrared fuze[1]. Moreover, it is suitable for the modern battlefield with the increasingly harsh electromagnetic environment. In the laser fuze system, the quality of electric pulse generated by the driving circuit is one of the significant factors which restrict the detection performance[2].

The MOSFET has been widely used as the core switch device in the design of the pulsed laser driving circuit. Sun and Yan used multiple MOSFETs to derive the LD[3-4]. The pulse width of driving circuit was more than 20 ns. Chen designed a driving circuit with the MOSFET (IXZ318N50). The rise time of the circuit reached 10 ns and the pulse width exceeded 20 ns[5]. The circuit of Xu had the 10 ns pulse rise time, and its pulse width was adjustable from 20 ns to 40 ns[6]. The driving pulse width of these circuits exceeded 10 ns, which is not sufficient for improving ranging precision.

Yang designed a laser power supply including the driving circuit and temperature control circuit with MOSFET (DE275). The rise time of the driving circuit was within 5 ns and the pulse width was less than 10 ns[7]. Xiong designed a driving circuit with 10 ns minimum pulse width and 3.5 ns rise time by using the MOSFET[8]. In general, the pulse width was within 10 ns and the rise time was less than 5 ns, which met the performance targets of the driving circuit for the laser fuze. However, the size of the MOSFET (DE275) is 21 mm×36 mm.

The working circumstance of laser fuze is harsh and complicated. Moreover, the size of projectile is limited. Then the driving circuit is required to possess the characteristics of high peak current, narrow pulse width, small volume and light weight[9]. In this paper, the spice models of high-speed switch and driving circuit are established, considering the parasitic effects caused by the circuit elements and PCB layout. Through the simulation and experiment, the influences of circuit parameters on the driving pulse are studied. Finally, a novel pulse laser driving circuit is devised with the pulse width within 10 ns, the rise time is less than 4 ns and the size is 19 mm×10 mm. The circuit is sufficient for laser fuze.

## 1 Operational principle

The operational principle: a pulse signal with the pulse width of 5 ns is generated by FPGA. The shaping circuit is used to process the signal to obtain a TTL level pulse with a pulse width of 5 ns[10]. Then the MOSFET driving chip converts the pulse signal to the CMOS level pulse signal. The high-speed MOSFET is driven by the CMOS signal to generate the LD driving pulse signal. The energy-storage capacitor provides a stable power supply voltage for LD and the protective diode keeps LD from the damage of the reverse voltage. The working principle of the driving circuit is presented in Fig.1.

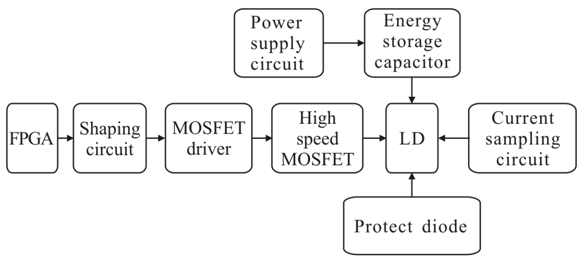



Fig.1 Principle block diagram of driving circuit

## 2 Modeling and analysis

### 2.1 High-speed switch circuit

High-speed switch is one of the main bottlenecks that restrict the development of semiconductor laser driving technology. The switching speed of the switch circuit determines the rise time and pulse width of laser pulse directly. Moreover, the high precision detection of laser fuze demands a nanosecond driving pulse. The high-speed MOSFET is appropriate for the pulse laser fuze with the peculiarities of fast switching speed, high peak current and simple driving circuit. However, the MOSFET is obliged to consider the parasitic parameters when being used as the high-speed switch. The high frequency equivalent model of the MOSFET with parasitic parameters taken into account is shown in Fig.2.

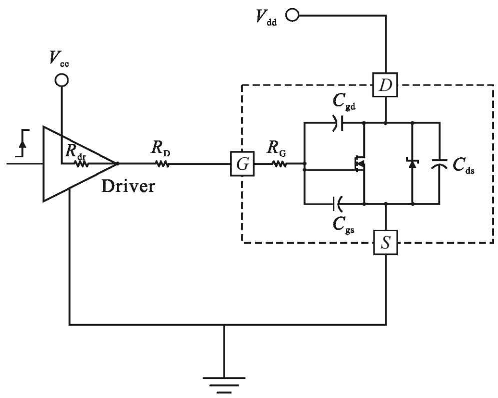



Fig.2 High frequency equivalent model of the MOSFET

In Fig.2, the driver is the front driver. $R_{dr}$ is the output resistance of the font driver and $R_D$ is the driving resistance. The high frequency equivalent of the MOSFET mainly includes the parasitic capacitances between the electrodes and the grid resistance. $C_{gd}$, $C_{gs}$ and $C_{ds}$ are the parasitic capacitances, $g_{gs}$ is the grid resistance[11]. Then the turn-on delay time $T_d$(on) is calculated from:

$$T_d(\text{on})=(R_{dr}+R_D+R_G)\times(C_{gs}+C_{gd}(\text{off}))\ln\left(\frac{V_{Dr}}{V_{Dr}-V_{th}}\right) \quad (1)$$

The conduction rise time $T_r$ is:

$$T_r=\frac{(V_{ds}-V_F)(R_{dr}+R_D+R_G)C_{gd}}{V_{Dr}-V_m}+(R_{dr}+R_D+R_G)$$
$$(C_{gs}+C_{gd}(\text{off}))\times\ln\left(\frac{V_{Dr}-V_{th}}{V_{Dr}-V_m}\right) \quad (2)$$

Correspondingly the turn-off delay time is:

$$T_d(\text{off})=(R_{dr}+R_D+R_G)\times(C_{gs}+C_{gd}(\text{on}))\ln\left(\frac{V_{Dr}}{V_m}\right) \quad (3)$$

Ultimately the shutoff time $T_f$ is:

$$T_f=(R_{dr}+R_D+R_G)C_{gs}\ln\left(\frac{V_m}{V_{th}}\right)+(R_{dr}+R_D+R_G)C_{gd}(\text{off})\times$$
$$\left(\ln\left(\frac{V_m}{V_{th}}\right)+\frac{V_{ds}-V_F}{V_m}\right) \quad (4)$$

where $C_{gd}$ (on) is the value of the gate-source capacitance when the MOSFET is activated, $C_{gd}$(off) is the value of the gate-source capacitance when the MOSFET is switching-off, $V_{Dr}$ is the amplitude of driving pulse, $V_{th}$ is the threshold voltage, $V_m$ is the miller voltage, $V_{ds}$ is the drain-source voltage for MOSFET shutdown and $V_F$ is the drain-source voltage for MOSFET turn-on.

According to the Eq. (1)–(4), aiming to derive a switching pulse with nanosecond pulse width, the coefficient of the charge and discharge circuit for the MOSFET are obliged to be vital. When the MOSFET is selected, $R_G$, $C_{gs}$, $C_{gd}$ (on) and $C_{gd}$ (off) are established. Compacting assembly and wiring reasonably are capable to reduce the stray parameters. A MOSFET driver chip is necessary to appease the demands of the laser fuze such as miniaturization, high reliability and strong anti-interference.

### 2.2 Analysis of the equivalent model of pulse laser driving circuit

In view of the high-precision detection and robust anti-jam of the laser fuze, it is essential for the driving pulse to possess the peculiarities of narrow pulse width and high peak current. Due to the limited energy of the missile-borne power supply, the driving circuit exploits the energy compression technology to obtain the high power driving pulse. Meanwhile, the circuit adopts a capacitor as the storage device. The basic circuit model of driving circuit is shown in Fig.3. Where, $R_1$ is the current-limiting resistance of the charging circuit, $C$ is the energy-storage capacitor. $S$ is the control switch, $R_2$ is the total resistance in discharge circuit and $L$ is the sum of the stray inductance[12].

Energy-storage capacitor accumulates the energy steadily when the switch $S$ is off. When the switch is on, the whole discharge circuit can be equivalent to a series RLC circuit due to the existence of distributed inductance. Then the discharge circuit can be turned into the under damping circuit by adjusting circuit parameters for the quick release of electricity from the capacitor. Eventually, the LD obtains an electric pulse with narrow pulse width and high peak current.

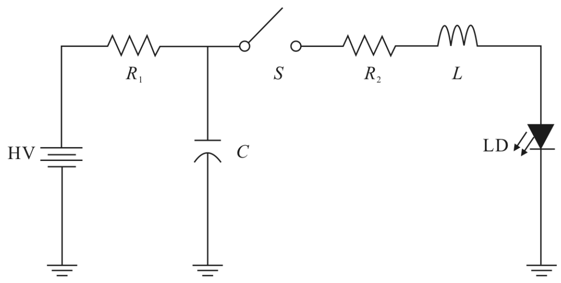



Fig.3 Principle of pulse laser driving circuit

### 2.3 Analysis of the impacts of pulse laser driving circuit

The driving circuit is the significant determinant that influences the detection performance of laser fuze. Therefore, it is crucial to meet the corresponding technical specifications for the driving circuit. Circuit size and capability of the driving pulse are in the priority of these indicators.

Circuit size is a momentous technical indicator in the design. The design space offered by the smaller-caliber munitions such as grenade, rocket and mortar projectile is limited contrasted with that of the guided missile and aerial-bomb. Moreover, it is unrealistic for the small-caliber munitions to install the transmitting and receiving optical systems on the missile wing. Besides, the size requirement of the driving circuit is predictable higher taking the subsequent filling and sealing process into account. Therefore, these factors are restrictive to the size of the drive circuit[13].

Pulse width, rise time and peak current are the specific manifestation of the capability. Narrow pulse is effective to improve the anti-jamming ability of laser fuze, especially in the harsh electromagnetic environment. Brief rise time is pivotal to enhance the detection precision of laser fuze. In addition, high peak current under limited power supply is significant to ensure the detection range, particularly in the case of limited missile energy[14].

OSRAM Company′s SPLPL90-3 is selected as the LD and its working parameters are shown in Tab.1.

**Tab.1 Electrical and optical characteristic parameters of SPLPL90-3**

| Parameters | Min | Typical | Max |
|---|---|---|---|
| Operating peak power/W | - | - | 90 |
| Operating peak current/A | - | - | 40 |
| Center wavelength/nm | 895 | 905 | 915 |
| Pulse width/ns | - | - | 100 |
| Minimum rise time/ns | - | 1 | - |
| Threshold current/A | 0.5 | 0.75 | 1 |

Ultimately, according to the above analysis results and actual operating parameters, the technical index of driving circuit is established. The driving circuit should be able to possess the following characteristics[15-16]: overall size within 4 $cm^2$, rise time among 5 ns, pulse width in 10 ns and peak current no more than 40 A.

## 3 Simulation and experimental analysis of driving pulse

The presence of parasitic parameters in LD and the distribution parameters in peripheral circuit have a serious effect on the quality of laser pulse. The main loop of the driving circuit considering these parameters is shown in Fig.4. Where $R_D$ is the driving resistance of the high-speed MOSFET. $R_1$ is the resistance limiting the supply current. $L_1$, $L_2$ and $L_3$ are the distributed inductances. $C_1$ and $C_2$ are the distributed capacitances. $R_Z$ is the damping resistance avoiding the excessive rise of the pulse amplitude from affecting the normal operation of the circuit. $C_3$ is the energy-storage capacitor offering a proper and steady voltage for the discharge circuit to retain the output pulse stable. $C_4$ is the parasitic capacitance of LD. $L_4$ is the parasitic inductance of LD. $D_1$ is the protection diode releasing the recoil voltage at both ends of LD rapidly to protect LD. $U_1$ is the high-speed MOSFET IRFR9N20D. $R_1$ is the driving current sampling resistor gauging the driving current of LD. Three parallel 1 Ω resistors are used as the monitoring resistor to reduce the parasitic parameters in the actual circuit.

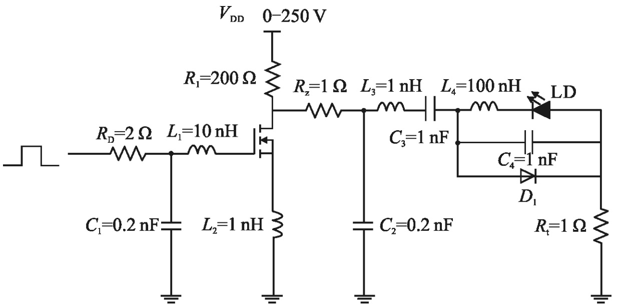



Fig.4 Main loop of the driving circuit

### 3.1 Simulation and experimental analysis of the supply voltage

The values of the energy storage capacitor and the damping resistance are 1 nF and 2 Ω respectively. Keeping the two parameters invariant and the value of the supply voltage was tinkered up to 50, 100, 150, 200, 250 V separately. The simulation and experimental results are shown in Fig.5, where the experimental waveforms are consistent with the simulation waveforms except the attenuation oscillation of the experimental waveforms. These oscillations stem from the existence of parasitic parameters, unsatisfactory input signal and inexactitude component values. Nevertheless, these limited oscillations are immune to the normal operation of laser fuze.

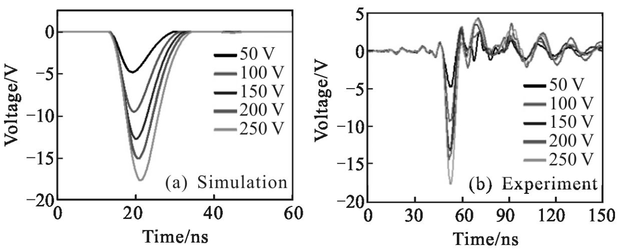



Fig.5 Simulation and experimental results when the supply voltage changes

Furthermore, the peak voltage increases as supply voltage rises, but the pulse width and rise time are almost unchanged. The rise time and pulse width of these waveforms meet the requirements. However, the peak currents exceed 40 A when the supply voltage surpasses 150 V, which is inoperable to the normal operation of the LD. Considering the requirements of laser fuze, 150 V is an appropriate value for the voltage.

### 3.2 Simulation and experimental analysis of the energy storage capacitor

The values of the supply voltage and the damping resistance are 150 V and 2 Ω respectively. The two parameters are kept invariant and the value of the energy-storage capacitor is tinkered up to 470, 820, 1, 4.7 nF separately. The simulation and experimental results are shown in Fig.6, where the existence of the attenuation oscillations in experiment is similar with Fig.5.

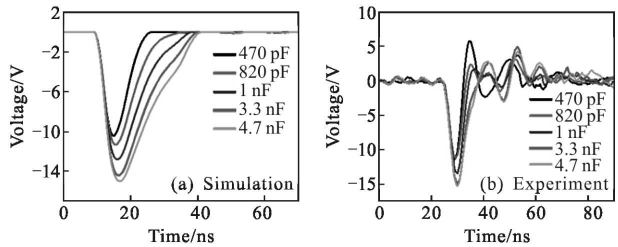



Fig.6 Simulation and experimental results when the energy storage capacitor changes

Besides, the peak voltage and pulse width enlarge with the increase of capacitance value, but the growth rate of pulse width in the experiment is minor compared with that of the simulation. Obviously, large attenuation oscillations caused by slight capacitance interfere with the normal operation of laser fuze. Furthermore, the pulse width of large capacitance is impractical for the high precision detection of laser fuze. Finally, 1 nF is a suitable value for the capacitor.

### 3.3 Simulation and experimental analysis of the damping resistance

The values of the supply voltage and the energy storage capacitor are 150 V and 1 nF respectively. These parameters are kept invariant and the value of the damping resistance is tinkered up to 1, 2, 3, 4, 5 Ω separately. The simulation and experimental results are shown in Fig.7, where experimental and simulation waveforms remain essentially the same, except the waveform oscillations at the pulse end.

In addition, the peak voltage abates tardily and the driving pulse widens minimally with the growth of the resistance. Nevertheless, the LD is probable to have a shortened life or structural damage by the large oscillation at a vital resistance. Hence, 1 Ω is not the ideal value for the resistance. Furthermore, the low peak voltage at a large resistance is unfavorable to the detection distance of laser fuze. Ultimately, 2 Ω is a reasonable value for the resistance.

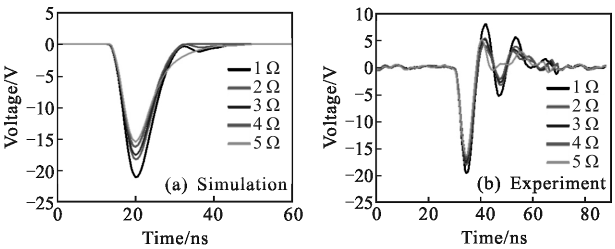



Fig.7 Simulation and experimental waveforms when the damping resistance changes

## 4 Application test

Several precautions such as compact layout of components, optimization of routing and discreet application use of vias have been adopted in the layout of the PCB. These precautions are beneficial to reduce the influences of parasitic parameters and stray parameters on the circuit. Finally, a driving circuit is acquired with the size of 19 mm×10 mm. The driving module is shown in Fig.8.

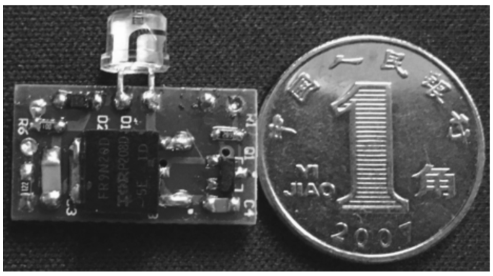


Fig.8 Laser driving module

The main parameters of the driving circuit are selected according to the simulation and experimental results. Consequently, the supply voltage is utilized as 150 V, the energy-storage capacitor is adopted as 1 nF and the damping resistor is selected as 2 Ω. And under such conditions, a narrow pulse with rise time of 4 ns, pulse width of 8.6 ns and peak current of 39 A has been obtained. The voltage waveform at monitoring resistor is shown in Fig.9.

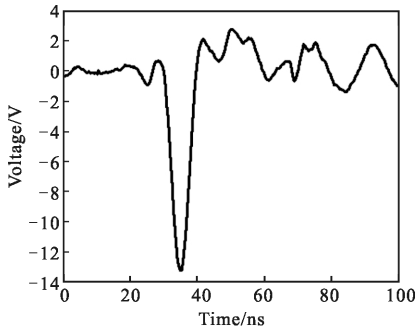
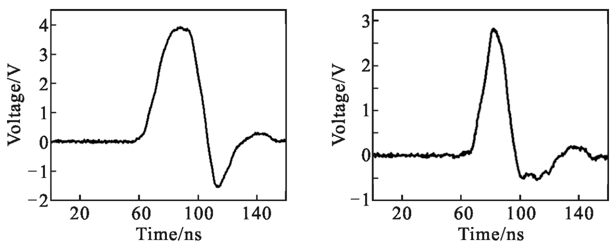



Fig.9 Voltage waveform at both sides of LD

Echo signals at different distances are shown in Fig.10. It is obvious that the echo signal is saturated at 2 m. Meanwhile, the signal at 5 m is broader than the transmit signal in virtue of interference scattering in air, broadening in lens and saturation of APD.




(a) 2 m detection with APD (b) 5 m detection with APD

Fig.10 Echo signals with APD at different distances

## 5 Conclusion

Aiming at the requirements of laser fuze, a compact and high-performance driving circuit is designed. Considering parasitic parameters and stray parameters, circuit models of driving circuit are established. Models with various factors considered is the basis of subsequent simulation and experimental verification. The effects of different parameters of driving circuit are analyzed by simulation and experiment. Furthermore, the results of the simulation and experiment are essential to select the best parameters in the design of driving circuit. Eventually, a driving circuit has been obtained with rise time of 4 ns, pulse width of 8.6 ns and peak current of 39 A.

It provides comprehensive support for high precision detection and miniaturization of laser fuze.

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