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Nanoseconds Switching for High Voltage Circuit Using Avalanche Transistors

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Abstract

The avalanche transistor is suitable for switching high voltage in kilovolts region. In this paper, a simple switching circuit consists of avalanche transistor is demonstrated. Sixteen of ZTX 415 avalanche transistors were used to switch a high voltage circuit up to 4.5 kV. A PIC16F84 microcontroller was utilized as control unit to generate input trigger. The result shows that the developed circuit was able to switch applied voltage up-to 4.5 kV with an average falling time is 2.89 ns.

Keywords: Avalanche transistor, High voltage, Microcontroller

1. Introduction

The operation of an electro-optically Q-switched laser requires fast switching of voltages in the multi-kilovolt regime (Chadderton, 19961; W. Koechner, 2006). Nanosecond scale high-voltage pulse generator or driver requires extremely high switching speeds. It is also capable of producing current outputs far in excess of that obtained from conventional circuits. In particular, the half-voltage of KD*P crystal Pockels cell is about 5.9 kV and needs the voltage to switch to zero within few nanoseconds in order to produce a short laser pulse (W. Koechner, 2006).

The common switching techniques include the use of MOSFETs (Alton and Sundararaja, 2004), SCRs and avalanche transistors (W. G Maguson, 1962; Molina *et al*, 2002, Jankee and Navathe, 2006, Lui Jinyuan *et al*, 1998). Each switch has its advantages and applications. The avalanche transistor mode is ideally suitable for this operation and has wide applications in laser Q-switching (Chadderton, 1996; E. S. Fulkerson & R. Box; C. Alton and R. Sundararajan, 2004; E. S. Fulkerson *et al*, 1997; ZTX 415 Datasheet,). Avalanche transistors are normally connected in series and operated close to their avalanche breakdown voltage. When triggered, all the transistors are switched on, and the transient pulse switching appears on Pockels cell. This effect changes the polarization state of Pockels cell which blocks or deflects light from passing through the crystal. The speed of switching and voltage applied across the crystals will determine the pulse duration of the laser output (W. Koechner, 2006)

In this paper, a simple circuit of avalanche transistors was developed to switch in the kilovolt regime. A series avalanche transistor was designed to switch up to 4.5 kV within few nanoseconds.

2. High Voltage Switching Circuit Design

The circuit shown in Figure (1) was designed to drive a Pockels Cell for a Q-switched Nd:YAG laser within a 0 – 4.5 kV DC voltage. This circuit includes three main components, high voltage power supply, trigger unit and control unit. The high voltage power supply provides DC voltage to Pockels Cell in the range of 4.5 kV. The trigger unit was used to chop the DC voltage to zero when initiated by control unit. The trigger unit circuit consists of a series of avalanche transistors such as illustrated in Figure (1).

The high voltage power supply is connected to trigger unit through two, series 1 MOhm resistors. The avalanche transistor ZTX 415 (TO-92) has maximum voltage collector-emitter (V_{CBO}) of 260 V (ZTX 415 Datasheet). It also possess high peak collector current of about 60 A with a pulse width shorter than 20 ns. Each avalanche transistor base is directly connected to emitter except the last one (Q_1). Transistor Q_1 is triggered via a control unit connected through a 100 Ohm resistor.

Initially transistor Q_1 is triggered, through the collector near the ground potential; resulting in about 300 V between the collector and emitter voltage across the second transistor Q_2. This second transistor, Q_2 experiences a nondestructive avalanche breakdown due to this over voltage. Consequently each transistor in turn experienced an even greater overvoltage due to a faster rise time and a shorter delay. Finally, transistor Q_{16} is turn to experience the high voltages, fast fall time.

The control unit was designed to operate in two modes, single and repetitive mode. For calibration purposes, the control unit was set to operate in a single mode. A single push button connected to PIC16F84A microcontroller was employed to perform this task. When, the push button is pressed, the microcontroller produced a single 10 µs pulse. This pulse was then triggered a BC547 transistor. The output of this transistor was used to trigger the first avalanche transistor.

3. Methodology

In this experiment a developed avalanche transistor circuit was calibrated. A Tektronix TDS 3054B digital oscilloscope with a bandwidth of 500 MHz and sampling rate of 5 GS/s was used to display and to measure the electronic signal. A high-voltage probe (Tektronix P6015A) with the maximum voltage of 20 kV DC or 40 kV for pulse was utilized to measure the high voltage supplied across the circuit. The flow chart of the measurement is shown as in Figure (2). The variable high voltage DC power supply in the range of 0 to 4.5 kV was connected directly to the developed circuit. For safety reason as well as to eliminate noise and to avoid electric shock the experimental setup was arranged properly. When the high speed switching occurs in kilovolt regime, electromagnetic induction (EMI) is expected to occur. This effect was avoided by designing the circuit on one layer of printed circuit board (PCB) and all the components were soldered and sealed properly. All the components and circuit are kept in isolated plastic case such illustrated as in Figure (3). The parameters such as the voltage switching, falling time and pulse duration were measured using the high voltage probe and oscilloscope.

4. Result and Discussion

The typical high voltage switching signal measured by Tektronix oscilloscope is shown in Figure (4). The input signal from control unit via PIC16F84A generated 10 microseconds pulse (bottom signal in Figure (4)). After the high voltage supply is switched to ground, the voltage is raised again within 90 microseconds (upper signal of Fig. 4). In this experiment, the maximum supply of DC voltage was 4.5 kV. Figure 5 shows the switching signal at 4.36 kV with a time scale of 4 ns time/division. The voltage reached its ground level within 3.04 nanoseconds. The falling time of high voltage switching was measured using Tektronix high voltage probe and Tektronix oscilloscope 5 GHz sampling rate.

The collected data of falling time were recorded. Figure (6) shows a graph of the switching falling time versus applied voltage. A nonlinear graph is obtained with the average of switching falling time of 2.89 ns. The developed circuit also produced negative voltage and small ripple in nanoseconds scale. The maximum negative voltages were measured and represented in Figure (7). The negative voltages were in linear relationship with the applied voltage. In certain case, this voltage could increase the Q-switching efficiency due to the full retardation of laser beam. For commercial purpose, the circuit should produce sharp pulse with small ripple. The high voltage supplied to the avalanche transistor caused it to change its shape due to the piezoelectric effect. This effect could be eliminated by adding RC component in the circuit. Furthermore, by using PIC microcontroller, the pulse duration of trigger signal easily adjusted and controlled. In addition, the developed circuit also able to operate in high repetition rate mode up to 1 MHz.

5. Conclusion

A simple high-voltage pulse switching circuit using avalanche transistor and PIC16F84A microcontroller was successfully developed and characterized. The maximum operation voltage was 4.5 kV with average falling time of switching pulse is 2.89 ns.

Acknowledgment

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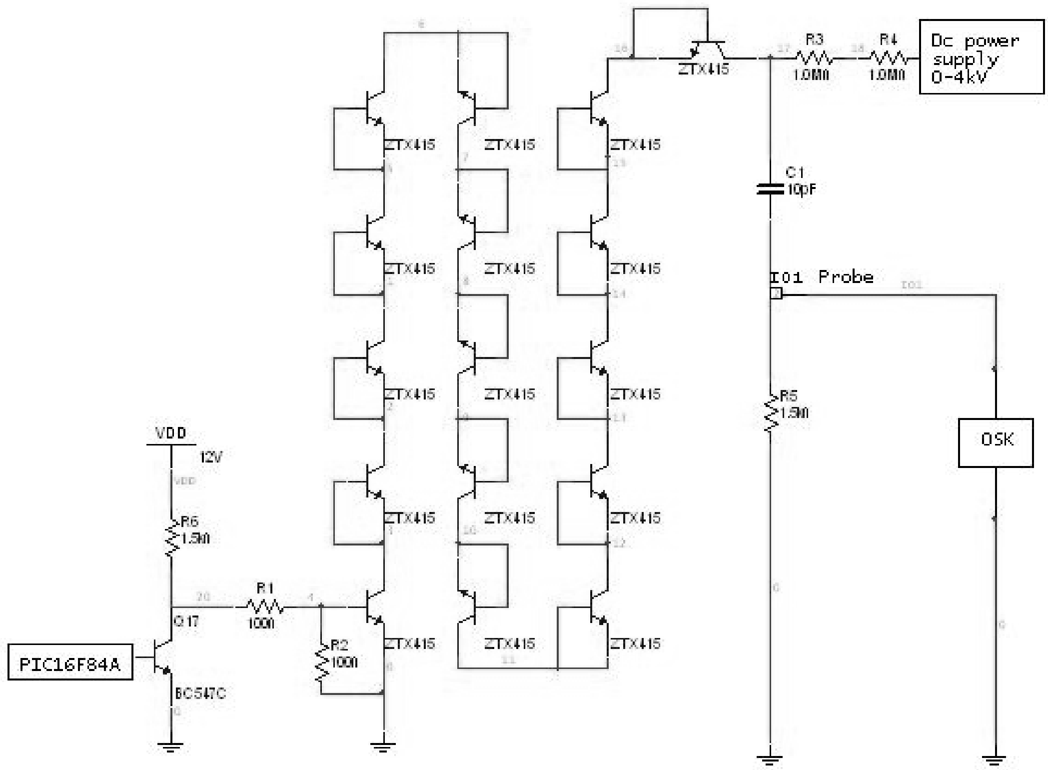

Figure 1. Schematic diagram of high voltage avalanche transistor trigger circuit

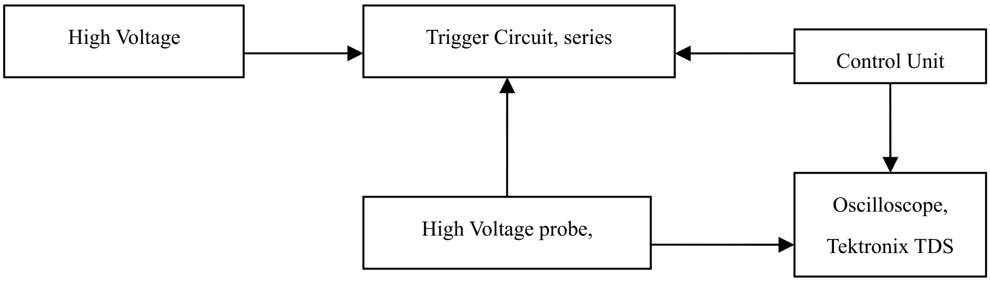

Figure 2. The flow chart of experimental work

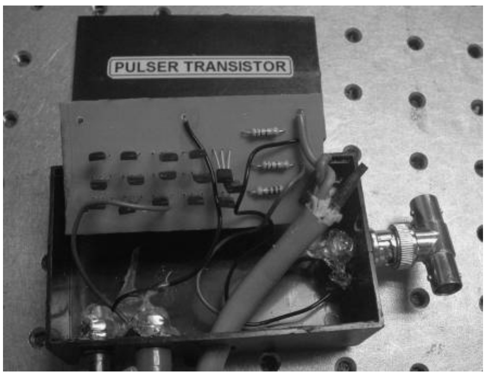

Figure 3. The developed avalanche transistor circuit on PCB in the plastic case

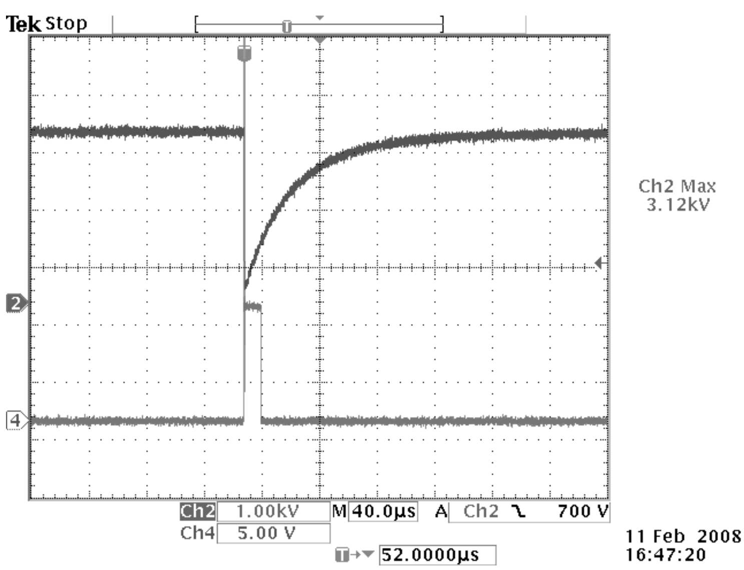

Figure 4. High voltage switching signal

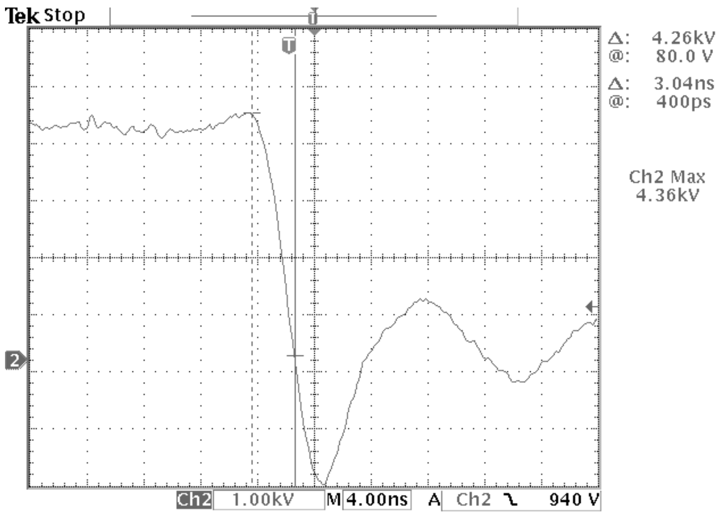

Figure 5. Typical result of nanosecond pulse

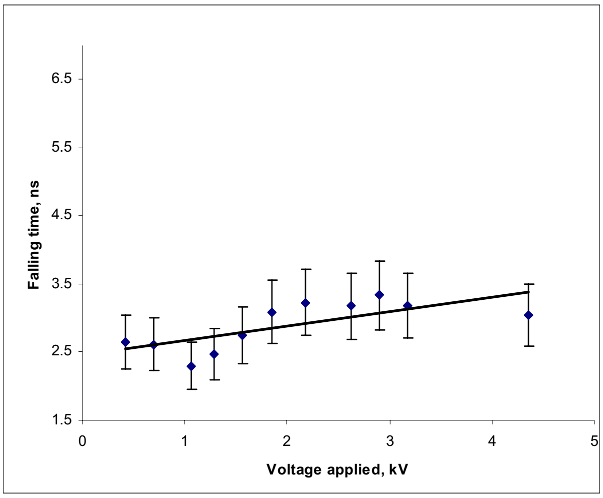

Figure 6. The graph of falling time versus applied voltage.

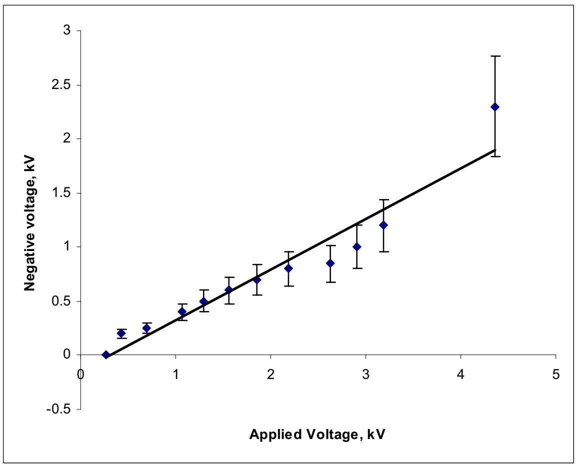

Figure 7. Negative voltage of high voltage switching