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HIGH VOLTAGE NANOSECOND PULSE SWITCHING CIRCUIT BASED ON AVALANCHE TRANSISTOR

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ABSTRACT

A very high speed switching circuit in kilovolt regime has been applied in laser diode driver, streak camera and laser Q-switching. The avalanche transistor is ideally suits to this mode operation and application. In this paper, a simple circuit to switch the high voltage in a few nanoseconds has been developed. Sixteen ZTX 415 avalanche transistors were used to switch 4.46 kV in 3.04 ns of falling time with 93.96 us of switching pulse duration. The result also shows that the switching pulse duration and falling time of circuit is independent on the operation voltage as well as the number of transistor.

Keywords: Avalanche transistor, High Voltage switching, Q-switching

INTRODUCTION

Operation of an electro-optically Q-switched laser requires fast switching of voltages in the multi-kilovolt regime [1, 2]. Nanosecond scale high-voltage pulse generators or drivers are required to have very extremely high switching speed and are capable to produce current outputs far in excess of that obtained from conventional circuit. For example, the half-voltage of KD*P crystal is about 5.8 kV and we need to switch this voltage that apply to Pockell cell quickly to zero in a few nanosecond [2].

The common switching techniques include the use of MOSFETs, SCRs and avalanche transistor [2-6]. Each switch has its advantages and applications. Avalanche transistor mode is ideally suitable for this operation and has wide applications in laser Q-switching [1, 6-8]. The avalanche transistors normally connected in series are operated close to their avalanche breakdown voltage. When triggered, all the transistors are switched on, and transient switching pulse appear on Pockels cell. This effect changes the polarization stage of Pockel cell which then 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 [2].

In this paper, a simple circuit of avalanche transistor has been developed to switch kilovolt regime. A series avalanche transistor was designed to switch 4.3 kV in nano-second scale.

HIGH VOLTAGE SWITCHING PULSE DESIGN

This circuit was designed to drive a Pockell Cell for Nd:YAG laser with 2 – 4 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 Pockell Cell in range of 4 kV. The trigger unit was used to chop the DC voltage which is controlled by the control unit. The trigger unit circuit consists of a series of avalanche transistors such as shown in Figure 1.

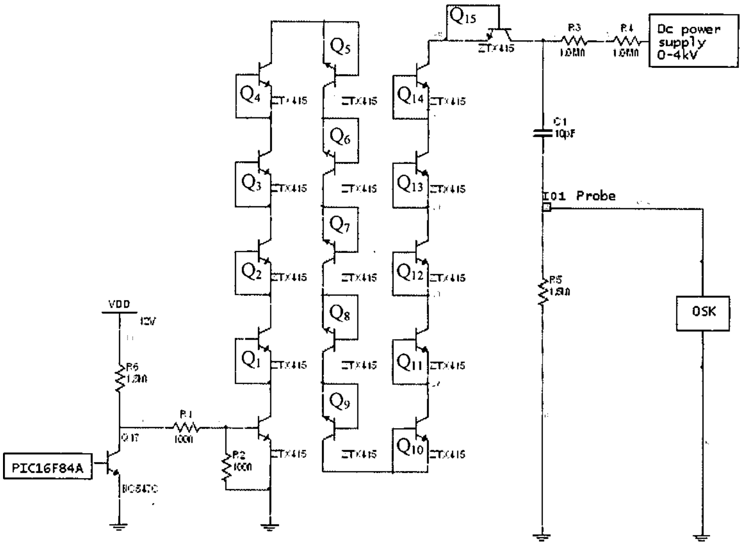

Figure 1: Schematic diagram of high voltage avalanche transistor trigger circuit.

The high voltage power supply is connected to trigger unit through a double 1 MΩ resistors. The avalanche transistor ZTX 415 (TO-92) has maximum voltage collector-emitter (V_{CBO}) of 260 V [1]. Beside that, it has very high peak collector current which is about 60 A with a pulse width shorter than 20 ns. Each avalanche transistor base is directly connected to emitter except for the first one (Q_1). This transistor Q_1 is triggered via a control unit which is connected through 100 Ω resistors. Initially the transistor, Q_1 is triggered, through the collector near the ground potential; resulting in about 300 V collectors to emitter voltage across the second transistor Q_2. This second transistor is suffering a nondestructive avalanche breakdown due to this over voltage. Consequently each transistor turns on, the next transistor suffers an even greater overvoltage resulting in faster rise time and shorter delay. Finally, the last transistor Q_{14} turns on and a high voltage, fast fall time pulse is produced [2, 8-10].

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 that is 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 then triggered a BC547 transistor. The output of this transistor was responsible to trigger the avalanche transistor.

METHODOLOGY

The developed trigger unit of avalanche transistor circuits was calibrated. A Tektronix TDS 3054B oscilloscope with a bandwidth of 500 MHz and sampling rate of 5 GS/s was employed to display the electronic signal. A high-voltage probe (Tektronix P6015A) with the maximum voltage of 20 kV DC or 40 kV for pulse was conducted to measure the high voltage supplied across the circuit. The schematic diagram of the experimental setup is shown in Figure 2.

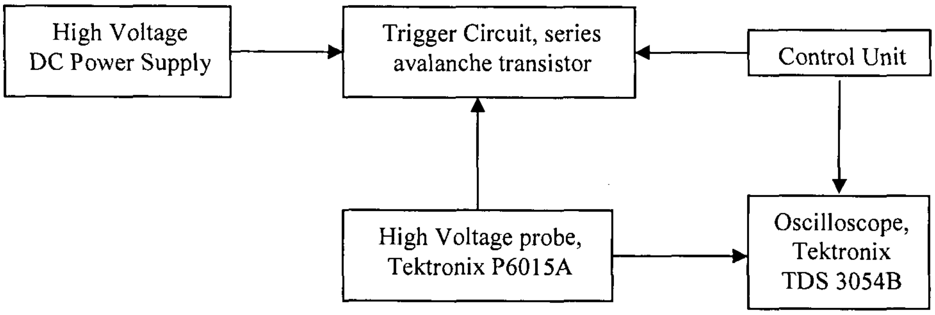

Figure 2: The schematic diagram of experimental setup

For safety purposes, the experimental setup was arranged properly to eliminate noise and to avoid electric shock. When the high speed switching occur in kilovolt regime, electromagnetic induce (EMI) is expected to produce. This effect was avoided by designing the circuit on one layer of printed circuit board (PCB) and all the components were soldered properly. All the components and circuit are kept in isolated plastic case. The parameters such as the voltage of switching, falling time and pulse duration were measured using the high voltage probe and oscilloscope.

RESULTS AND DISCUSSION

In order to optimize the operation voltage of avalanche transistor, a primary experiment was carried out. The number of avalanche transistor was added and the operation voltage was measured. The result of experiment is presented in the graph shown in Figure 3. Obviously a linear relationship obtained indicates that, the operation voltage of avalanche transistor is proportional to the usage of avalanche transistor. The large number of avalanche transistors require high voltage to operate the circuit.

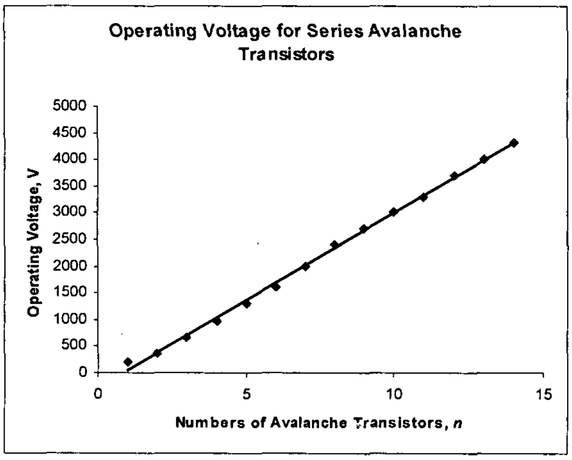

Figure 3: The operating voltage for different numbers of transistors in avalanche mode operation.

In general, about half to two-third of the DC voltage across each avalanche transistor would be applied to the load when the transistor is in avalanche mode. However to maintain the transistor in this regime, the DC voltage across every transistor is limited to V_{CBO} = 260 V [11]. The maximum voltage across transistor is, $V_{max} = n$ (V_{CBO}), where n is number of avalanche transistors [1]. Therefore the number of avalanche transistors of Zetex 415 for a 4 kV output pulse is given by:

$$n = \frac{V_{max}}{V_{CBO}} = \frac{4000}{260} = 15.38 \cong 16 \qquad (1)$$

The number of avalanche transistor is depending on the voltage applied and circuit configuration of avalanche due to current flow. In this developed trigger unit, only 16 transistors have been employed in the trigger unit, corresponding to apply voltage of 4 kV. If the operating voltage is lower than threshold voltage, no signal will coming out. When the operating voltage is higher than the maximum voltage of V_{CBO}, the transistor will be broken down immediately or having very short lifetime. Furthermore, the circuit was also self triggering which means it works without trigger signal from control unit. There is also possibility to produce multiple pulses without single trigger signal.

The typical result of nanosecond switching pulse is shown in Figure 4. In this experiment, the maximum voltage of operation was 4.36 kV and the falling time from maximum voltage to zero was 3.04 ns as in Figure 4. The circuit will produce small ripple due to piezoelectric effect (the same as in Pockel Cell).

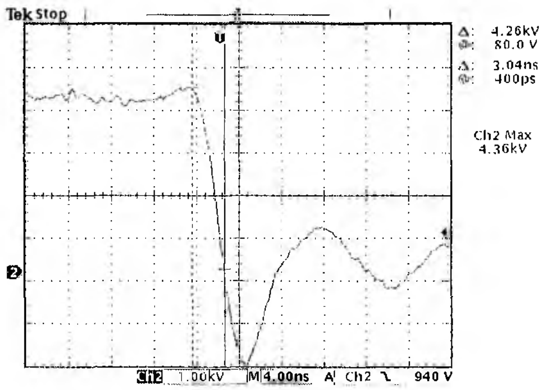

Figure 4: Typical result of nanosecond pulse switching in high voltage regime.

The duration of the switching pulse is measured using Tektronix oscilloscope. The switching duration is similar to the rise time of pulse signal and it can be measured using oscilloscope. Typical results of switching signals are shown in Figure 5. As shown in Figure 5, the rise time of pulse was 93.96 μs. From the experiment, the fall time and rise time of series avalanche transistor circuit is independent on the operation voltage as well as the number of avalanche transistors. It means, in avalanche mode, all the series transistors become very close to ground and switch the high voltage when the last transistor is triggered.

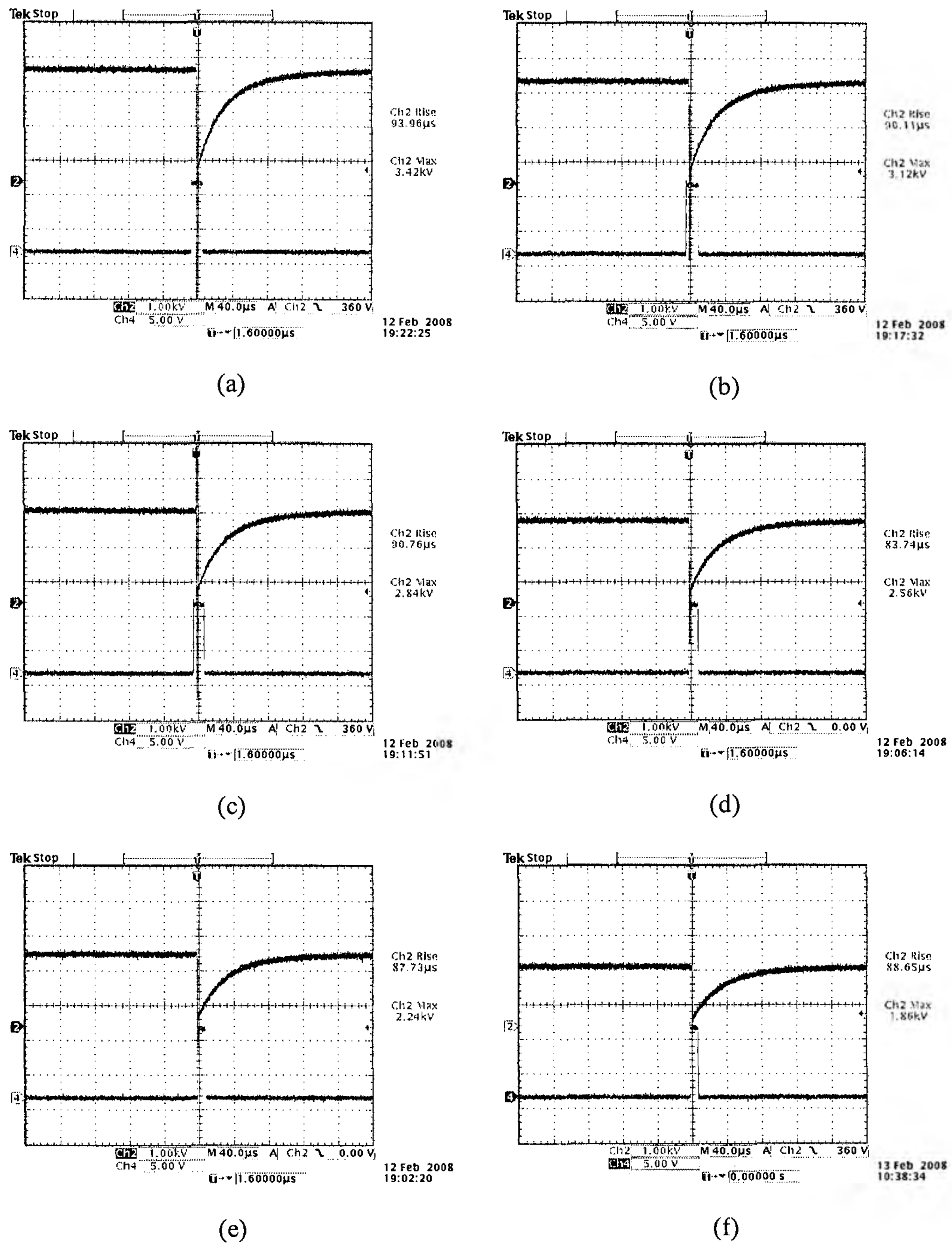

Figure 5: Experimental switching signals for various of voltages (a) 3.42 kV, (b) 3.12 kV, (c) 2.84 kV (d) 2.56 kV, (e) 2.24 kV and (f) 1.86 kV with a rise time of 93.96 µs.

CONCLUSION

A simple high-voltage pulse switching circuit was successfully developed and characterized. The falling time of switching pulse is 3.04 ns with maximum operation voltage 4.36kV. The switching duration and fall time of the avalanche transistor circuit is independent of the number of avalanche transistors and operation voltage. This circuit is suitable to driver Pockel Cell for laser Q-switching.

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