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Conference Paper · April 2023

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High voltage picosecond pulse generation by an avalanche transistor stack on microstrip PCB

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ABSTRACT

A sub-ns pulsed voltage driver was developed using a transistor stack fabricated on a printed circuit board (PCB) in micro-strip configuration and operated in avalanche mode. The stack consisted of 9 stages of 2N5551 transistors, and was biased with a 3 kV dc supply. The switched output was observed with a 50 ohm load, transmitted through a 0.5 meter cable after using a high voltage attenuator of 20 dB and a low voltage co-axial attenuator of 24 dB. The rise time of the leading edge of the voltage pulse was of 225 pico second (ps), amplitude of -1.2 kV with a full width at half maximum (FWHM) of 500 ps. This will be used for gating a micro-channel plate for time resolved studies of x-ray emission from capillary discharge plasmas as well as laser produced plasmas.

Keywords: High voltage fast pulsed generation, avalanche mode operation, micro-strip line, MCP gating.

1. Introduction

High voltage pulses of sub-ns durations (100's of pico seconds) are mainly used in applications like gating of micro channel plate (MCP), fast framing camera [1, 2], Pockels cell driver [3], ultra wideband radars [4,5] and for biological cell studies [6] etc. There are several types of switches recently being used to generate such fast rising pulses like drift step recovery diodes (DSRD) and silicon avalanche sharpner (SAS) diodes [5], pressurized oil spark gaps [7] and avalanche transistors [4, 8, 9] etc. Among solid state pulsers, avalanche transistor based circuits fall in the low power regime but they are simple, compact and of low cost.

There are predominantly two types of circuit configurations which use multiple transistors in series. The first is series stack of transistors [5, 10] and second one is Marx bank type circuit. In a series stack, all the transistors are directly connected which behaves as one switch and turning it on provides a pulsed output. The voltage of the biasing supply for such stack is set according to the number of transistors and suitable avalanche voltage of one transistor. On the other hand, the Marx bank circuit consists of multiple stages in which a capacitor of each stage is charged to same supply voltage but they are connected in series when the switch of each stage is turned on. From this configuration, a voltage output higher than the supply voltage can be accomplished. Generally, for pulse amplitude higher than 1 – 2 kV the Marx bank configuration consisting of series stack of three or more transistors are more popular [3,8,9,11-13] since using biasing supply voltage of greater than 5 kV poses insulation problems in compact PCB designs.

Baker et al. [11] had reported pulse outputs of ~1 ns rise time, amplitude of 2 kV across 50 ohm load in 1991 using bipolar junction transistors in avalanche mode. Another work by Oak et al., [12] also showed rise times of ~1.5 ns, with output voltage of 3.3 kV across open loads by Marx bank circuits in the same year.

Later Rai et al., [13] reported pulses with a rise time of 0.8 ns and amplitude of ~4 kV across a 680 k ohm load in the year 1994. For first time, Liu et al., [8] reported in 1998 a Marx bank circuit generating 250-300 ps rise time 4 kV pulse on 50 ohm load without any pulse sharpening device. The circuit was fabricated as microstrip tracks on a double sided printed circuit board. And quite recently Li et al., [9] showed ~150 ps rise time pulsed output on 50 ohm load by using a tapered microstrip line and single transistor in each stage.

On the other hand, in case of series stack circuit the pulse rise time of ~2.5 ns was reported by Upadhyay et al., [10]. By configuring series stack as a tapered line using discrete capacitors, pulse rise time of 0.8 ns was achieved by Krishnaswamy et al., [6]. It is worth noting here that circuits made on a normal PCB, both Marx as well as series stack could only achieve rise times of 1-2 ns range. This is because in case of a microstrip PCB, the inductance of stack is minimized/nullified by shunt capacitors formed at pads of the components, leading to overall faster rise times [3,8,9].

For time resolved studies of x-ray emission from capillary discharge x-ray laser and high power laser produced plasmas which are typically of few nano seconds duration, a very short (sub-ns) ~1 kV pulsed gating of the MCP is required. Although, researchers have produced 1 kV pulses using Marx bank circuit, the number of transistors in it is usually quite higher [2,3,11]. In order to solve this, Marx bank circuits with a single transistor in each stage had also been reported [4,9] but it still had 14 transistors and required very careful fabrication of the PCB. As an alternative, we constructed a series stack circuit with nine avalanche transistors in tapered micro-strip configuration and could generate 1.2 kV pulse with rise time of ~225 ps (20% to 80%) and FWHM of 500 ps across a 50 ohm load. The details are presented here.

2. Design and description

The schematic of the designed circuit is shown in the Figure 1. The circuit consist of nine 2N5551 transistors connected in series and for equal voltage sharing among them a resistive network of equal resistor R2 is connected as shown below.

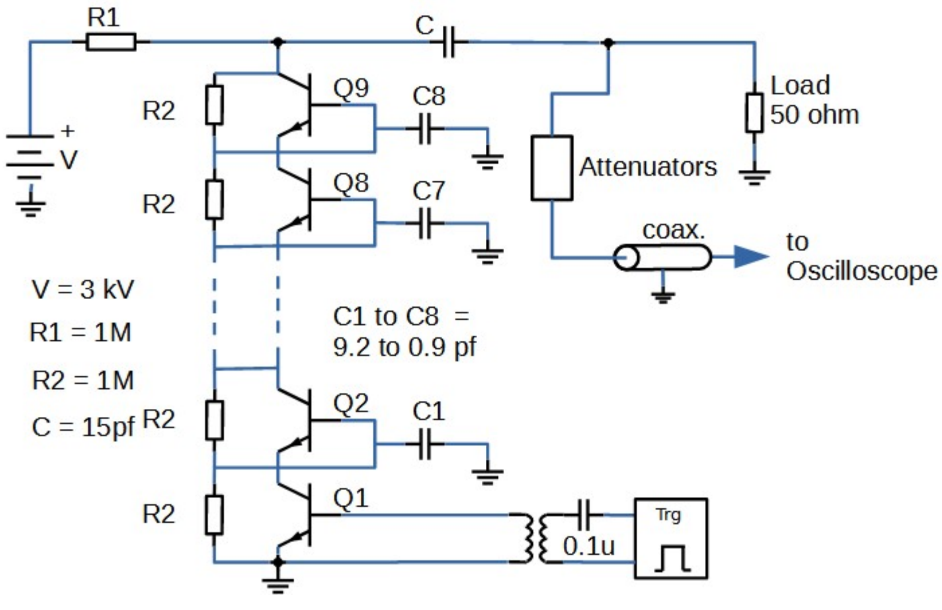

Figure 1. *Schematic of avalanche transistor stack pulse generator*.

The stack is biased by a high voltage supply through a resistor R1 and output is decoupled by a small ceramic capacitor C. The first transistor from the circuit ground was triggered and isolated by a toroidal ferrite cored transformer to protect low voltage trigger circuit/generator. The load is connected at the other end of the decoupling capacitor. For present measurements a combination of a high voltage high bandwidth 20 dB attenuator (make: Barth) and a 24 dB low voltage coaxial attenuator was used. The pulse was measured using a 4 GHz digital oscilloscope (Lecroy) with 50 ohm input impedance.

The circuit was fabricated on a double sided FR4 PCB which was etched coarsely to get tapered microstrip line as shown in photo in Figure 2. The line impedance from the first transistor up to fifth was tapered from 20 ohm to 50 ohm. The lateral copper strips with ground plane form capacitors with fibreglass PCB material as dielectric of $\varepsilon_r = 4.6$. Therefore, the capacitors C1 to C8 appears at the collector of the next transistor. Last four transistors continue on 50 ohm line. First we have experimented with the gradual steps of tapering and for that extra discrete capacitors soldered on the strips were used in first two stages but later on found out that removal of them made no difference in the rise time of the pulse. It can be also seen that serial in-line pins were used to insert transistors so that the avalanche voltage of each individual transistor may be checked and if found less than 350 V it can be replaced. In this way, setting up of a separate testing jig to select best suited transistors was avoided.

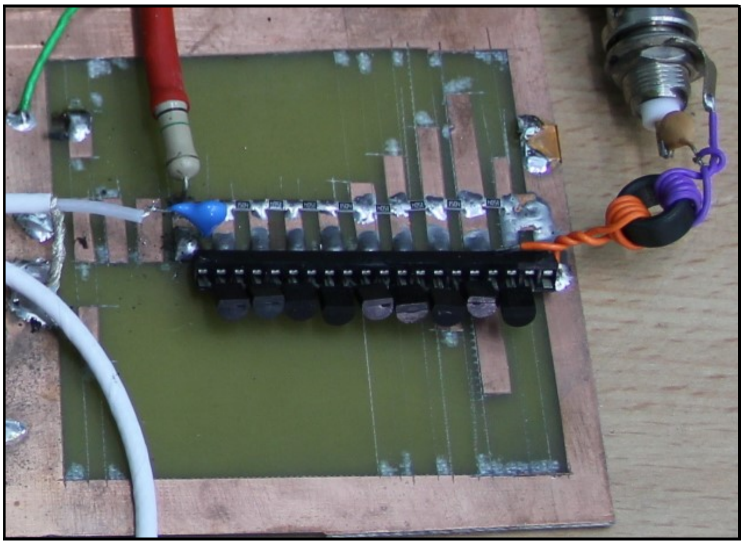

Figure 2. *Photograph of the avalanche transistor stack pulse circuit.*

3. Result and discussion

The resulting waveform is shown in Figure 3. The rise time (20% to 80%) measurement done by scope is shown in figure as 225 ps but 10% to 90% time is ~270 ps which is in the range obtained by Lui et al., the same transistors but obtained from the Marx bank circuit [8]. It is one order better than series stack circuit [10] and better than that of earlier Marx circuits [11-13] where microstrip PCB was not used.

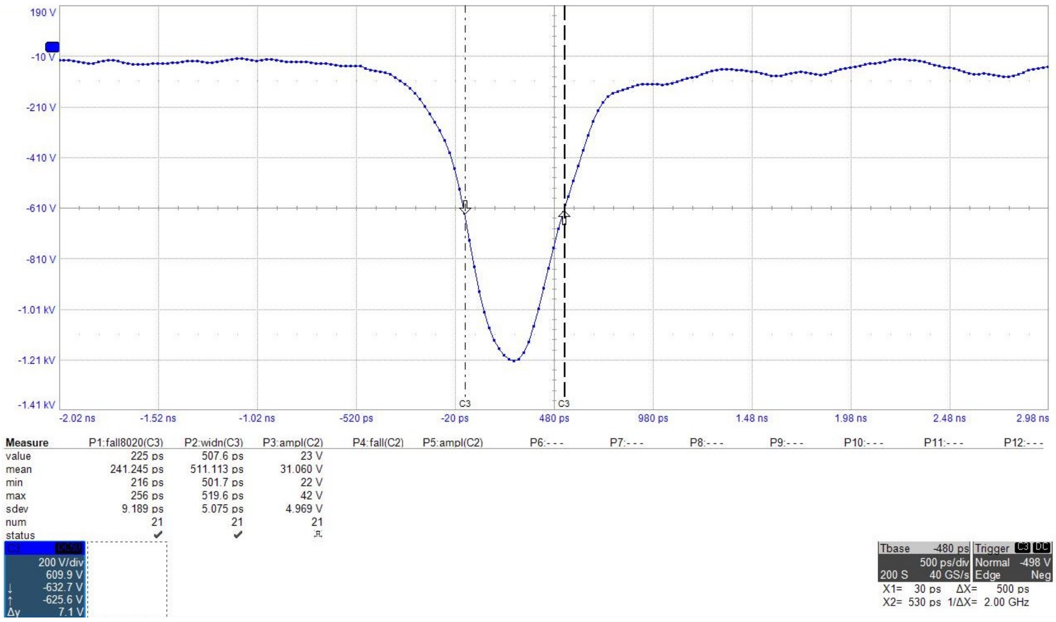

Figure 3. *Output pulse waveform of the pulse generator across 50 ohm.*

During the initiation of the pulse, the rise in the voltage is slower which could be due to charging of input capacitance of the first transistor by the trigger circuit. The stack was gradually build-up after first 5 transistors because we wanted to observe changes in the rise time with increase in numbers of switches. In a series stack circuit there is no increase in voltage, as it happens across switches of a Marx bank circuit due to stage capacitors. But the voltage across subsequently higher stages of the series stack, reaches beyond break down voltage V_{CBO}. So due to tapered line construction, the transistors at higher voltage levels go into current-mode second breakdown regime faster and the current through the stack also grows [6, 14]. It was observed that the rise time of the pulse was faster (changed from ~700 ps to ~230 ps) when numbers of transistors were increased from 5 to 9. There is also effect of cancellation of inductance of each stage by grounded capacitors due to microstrip design [8, 9, 11]. The number of transistors in stack can be increased up to 14 that would enable us to refine the tapering of the microstrip line impedance. There is definitely scope of further improvements because circuit was constructed coarsely. The new SMD avalanche device like FMMT417 can be used and this stack can be used as a stage of Marx bank circuit to achieve 150 ps rise time [9] as well as pulse of ~300 ps FWHM.

4. Conclusion

It has been shown that the series stack circuit using avalanche transistor can also be used to generate 1.2 kV pulse with rise time of ~225 ps (20% to 80%) and of 500 ps (FWHM) across 50 ohm load. It is very simple and cost effective design and well suited to applications like MCP gating since the voltage amplitude is in range of ~1 kV. The effective inductance of a stack would have severely deteriorated the rise time performance if microstrip line based PCB construction was not used.

Acknowledgements:

The authors would like to express their thanks to Dr. S.Barnwal for their support in understanding MCP unit and its implementation in further measurements using this pulser.

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