PULSE GENERATION AND MEASUREMENT OF RADIATED WAVEFORMS FROM AN OPTICALLY ACTIVATED IMPULSE GENERATOR

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ABSTRACT

The generation of extremely narrow, high peak power pulses using an optically activated impulse generator has been demonstrated. Radiative measurements at 1 Hz PRF have been conducted by pulse biasing this device up to 15 kV and subsequently triggering the device with an optical pulse from a Nd:YAG laser. The measured pulse from a wide-band antenna had a pulsewidth of 1.5 ns with a risetime of 900 ps. The frequency spectrum of this radiated waveform ranged from 50 MHz to 1 GHz.

INTRODUCTION

The demonstration of photoconductive switches operating at large bias voltages and generating multi-megawatt powers has stimulated the research of optically activated semiconductor switches in the pulsed power community [1]. Initially, research emphasis was given to the generation of high peak power pulses with risetimes in the multi-nanosecond regime. However, in recent years there has been an increased interest in the generation of sub-nanosecond risetime pulses with high peak power and with very short durations. Research efforts have resulted in substantial progress in the reduction of risetime and pulsewidth. The generation of pulses with sub-nanosecond rise times has been reported by Pocha et al [2] and Zutavern et. al.[3].

The generation of high peak power pulses with sub-nanosecond risetimes and very short durations using an optically activated semiconductor switch becomes complicated due to the available triggering optical pulses and the recovery time of the switch material. In addition, in the case of the semi-insulating (SI) GaAs switch, the switch lock-on behaviour [4] tends to sustain the switch conduction state long after the termination of the optical pulse One way to control the pulse width of the output pulse is to decrease the dimensions of the pulse forming line (PFL) used for the energy storage medium. The output pulse width is approximately equal to the round-trip traveling time of the wave in the PFL. However, as the physical dimensions of the PFL approach the values necessary to achieve the narrow pulsewidth (< 1 ns), the diminished energy storage capability of the PFL and the large stray inductance between the PFL and switch electrode pose a serious problem.

Utilization of the radial transmission line structure as the PFL has several advantages when compared to the typical microstrip line structure or coaxial transmission line structure. The geometrical effect of this radial transmission line creates a large electrode area, so that a large electrostatic energy may be stored. In addition, the impedance transformation due to the impedance variation between the inner and outer radii of the metallized conductive layers of this radial line results in a voltage gain [4] Kim et. al. [5] have experimentally demonstrated the generation of nanosecond pulses with voltage gain using an optically activated hybrid pulser

Impulse technology [6] refers to the free-space transmission of a short-duration pulse having a very high peak power and a broad frequency spectrum that extends from near DC to several gigahertz. The generation and characterization of the switch waveforms represents only part of work needed to obtain an understanding of this emerging technology The incorporation of a wide band antenna with the switch and the measurement of the actual radiated waveforms are also needed to complete this effort For this purpose, the radiated waveform obtained from driving a wide band antenna with an optically activated impulse generator has been generated, measured, and characterized for several switch voltages.

OPTICALLY ACTIVATED IMPULSE GENERATOR

The optically activated nanosecond impulse generator used a radial transmission line structure to enhance the energy storage capability as well as to produce output voltage gain The difference between the optically activated hybrid pulser and the optically

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activated monolithic impulse generator is in the choice of the dielectric medium for the energy storage. The optically activated hybrid pulser consists of a discrete GaAs switch and the radial transmission line. The optically activated monolithic integrated pulser combines the functions of the energy storage, radial transmission line, and the switch into a single large SI-GaAs wafer

The structures of the optically activated impulse generators are similar except for the dielectric medium. The schematic diagram of the optically activated hybrid pulser is given in Figure 1. As shown in Figure 1, the radial transmission line, in which the electrostatic energy is stored, was realized by fabricating a disc-shaped conductive layer on both sides of the cylindrically shaped teflon The radius of the inner edge of the radial transmission line was selected to have a characteristic impedance of 50 ohm. The radius of the outer edge of the radial line was determined by the design criterion of a 1 ns pulsewidth Therefore, the characteristic impedance of the radial line varied from 50 ohm at the inner edge to 10 ohm at the outer edge. The 3 mm gap GaAs switch was located at the center of the radial transmission line structure.

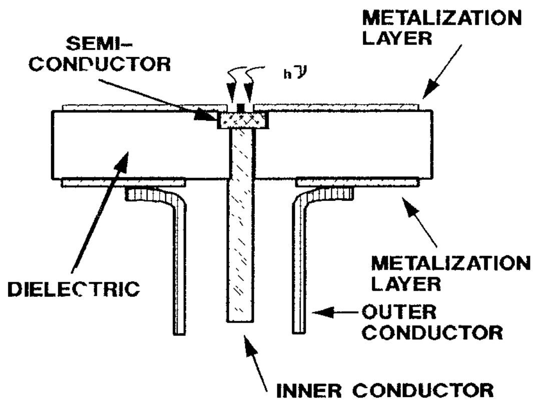

Figure 1: Optically Activated Impulse Generator

For small impedance transformation ratios (<2), the wave behavior in the radial transmission line can be expressed by a simple mathmatical expression In particular, in the case of the impedance matched circuit and negligible on-state switch resistance, the output pulse generated by the optically activated impulse generator can be expressed as follows:

$$V_{out} = (V_o/2)[Z_{ir}/Z_{or}]^{1/2} \qquad (1)$$

where Z_{ir}, Z_{or} are characteristic impedance in the radial line at the inner and outer diameters of the electrode, respectively, and V_o is the bias voltage. The first term is identical to that of a matched PFL The second term expresses the voltage transformation This term is referred to as the voltage gain factor The anticipated voltage gain factor of the fabricated radial transmission line is about 2 2, based on the expression in Equation (1)

EXPERIMENTAL RESULTS AND DISCUSSION

The initial investigation focussed on the experimental procedures leading to the better understanding of the behavior of the nonlinear transmission line and the switch mechanisms In this experimental work, a 50 ohm resistor was used as a dummy load.

The voltage waveforms were measured using a scope as the terminating load [5] A 50 ohm coaxial structure was pressure fitted to the ground side electrode of the impulse generator. An SCR-transformer circuit was used as the charging pulser After charging the radial transmission line with the charging pulser, optical light pulses from the laser diode array triggered the device. The voltage waveforms, ranging from 8 kV to 12 kV were measured with wide bandwidth Barth attenuators connected directly to a Tektronix 6 GHz transient digitizing oscilloscope. At 8 kV and 12 kV bias voltages, the output voltage amplitude were about 5 2 kV and 9.5 kV, respectively. Thus, the voltage gain factors at 8 kV and 12 kV bias voltages amount to 1 3 and 1.58, respectively As the bias voltage increases, the magnitude of the voltage gain becomes large. In addition, the risetime of the generated pulses sharpens

After characterizing this device using dummy load, the optically activated impulse generator was connected into the wide-band antenna and further investigations were conducted on the radiated waveforms. The radiative measurements were performed in the anechoic chamber of the Unconventional Beam and Damage Effects Function (UBDEF) facility, U.S. Army MICOM, Redstone Arsenal, AL. The radiated waveforms were measured using a Prodyne 3 GHz D-dot probe and a Textronix 7103 equipped with a digitizing camera system. The derivative field was measured for several switch voltages at a range of 6 meters.

The switch wave forms were radiated using a large TEM horn antenna The antenna was well characterized, having a flat gain across a half-beamwidth of 45^0 and capable of supporting pulse rise times of less than 200 ps. The five foot plates, with a 90^0 spread angle and 80^0 divergence angle, had a quarter-wave ring frequency of 50 MHz

The switch assembly was first configured in the lab. and tested to verify its operation using a Litton P-3 Nd:YAG laser system. Because of the slow risetime of the Q-switched optical pulse, there was some concern that the switch waveform would be too slow to radiate effectively. The laser output was attenuated to produce a total output through the fiber optic of 10 uJ After verifying the operation of the switch, the optically activated impulse generator was moved into the anechoic chamber and attached to the horn antenna, which was elevated to a height of 3.5 m. The elevation of the antenna unfortunately resulted in an undesirable cable length of 4.6 m. Connections at the antenna and at the switch were made using HN cable connectors

For the radiation measurements, the switch was operated at voltages ranging from 6 kV to 15 kV. The derivative waveforms were then integrated and scaled to determine the peak fields and the risetime for each voltage These results are presented below in Table 1. Representative waveforms are shown in figures 2 and 3 for bias voltages of 9 kV and 15 kV, respectively. It should be noted that the pulse waveform was very repeatable for all bias voltages.

Bias Voltage	Peak Field	Rise Time
9 kV	410 V/m	1100 ps
10 kV	475 V/m	1100 ps
12 kV	650 V/m	1000 ps
13 kV	690 V/m	950 ps
15 kV	860 V/m	900 ps

Table 1: Radiated Waveform Parameters

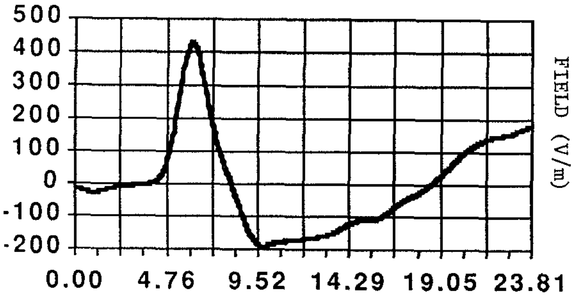

Figure 2: Radiated pulse waveform (V/m)for bias voltage of 9 kV.

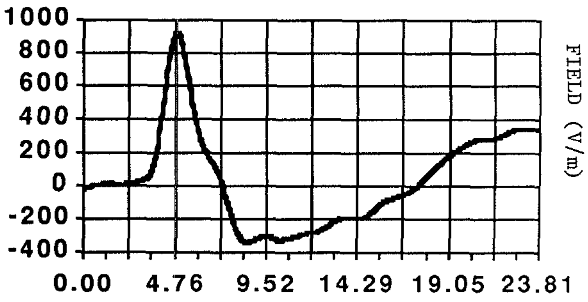

Figure 3: Radiated pulse waveform (V/m)for bias voltage of 15 kV.

The first observation to be made is the fact that the field risetimes were much less than the optical pulse risetime of several nanoseconds. This fact indicated that the switch was indeed operating in the avalanche mode. Because the cable interface to the radial line was not optimised, and considering the losses due to the slow risetime (using a Q-switched laser) and the long cable lengths, the actual switch risetimes are estimated to be on the order of 500 ps for the higher bias voltages. With an improved cable interface, the pulse risetime presented to the antenna would be much improved, resulting in an improved radiation efficiency and increased field strength for each voltage.

Considering the switch operation, the actual output voltage amplitude at 15 kV pulse bias voltage was only about 12 kV. Compared to the expected voltage gain factor 2.2 of this impulse generator (due to the impedance transformation), the gain factor of the obtained waveform at 15 kV bias voltage was only 1.6. The difference between the calculated gain factor (2.2) and the experimentally obtained gain factor (1 6) at 15 kV bias voltage is due to several factors, such as voltage drop in the semiconductor, impedance mismatch at the junction region, a slow risetime optical trigger, and the use of overly simplified transformer model.

As shown in Table 1, the risetime of the generated pulses decreases as the bias voltage goes up This may be due to an improvement in the avalanche-like switching mechanism, which would also improve the radiation efficiency.

CONCLUSION

Radiative measuments from an optically activated impulse generator using a wide-band antenna have been conducted at various voltages ranging from 6 kV to 15 kV. The peak field improved substantiially as the bias voltage was increased from 9 kV to 15 kV. This may be attributed to the faster risetime at higher bias voltages, which can be radiated more efficiently. The range of the frequency spectrum from this 1.5 ns pulse extends from 50 MHz to 1 GHz

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