SPARK GAP TRIGGERING WITH PHOTOCONDUCTIVE SWITCHES

J.R. Mayes and W.J. Carey
Applied Physical Electronics, L.C.
602 Explorer Austin, Texas 78734

W.C. Nunnally
The University of Missouri-Columbia
Columbia, Missouri 65201

Abstract

Photoconductive switches are well suited for triggering spark gaps since the triggering event is short and requires very little energy. Photoswitches offer fast-rising pulses of short duration with voltage levels of several 10's of kV and 10's of ps jitter and can be very simple in design, whereas typical trigger sources require multiple stages to generate 10's of kV needed to effectively trigger a spark gap of the same potential and usually suffer from slow risetimes. This paper presents methods aimed at triggering spark gaps with photoswitches. Both linear and non-linear photoswitches are discussed and their associated problems are presented.

Introduction

General spark gap configurations include the laser-triggered, the trigatron, and the field distortion. This paper addresses potential triggering methods for the trigatron and field distortion spark gap types. Triggering spark gaps is relatively simple for most applications; however, for low jitter applications, the non-laser triggering methods can become quite complex, often requiring UV preionization and ultrafast rising trigger pulses.

The photoconductive switch is a good candidate for triggering spark gaps due to its low jitter, low energy, and fast rising voltage pulse delivery. The nonlinear photoswitch, which requires only a few photons for switch closure, is especially appealing due to its small package size and low optical energy requirements.

This paper presents several photoswitch–based techniques for triggering the trigatron and field distortion spark gaps. Basic circuit layouts are presented with simulation results. Each technique is followed with associated advantages and disadvantages.

Background

The closure of a spark gap is a statistical process; however, the breakdown process is sequential. Consider the illustration shown in Figure 1, in which the spark gap is closed by overvolting. Initially, the spark gap voltage is set just below the statistical breakdown level, V_{SB}. The time for breakdown process to occur is dependent on four events: (1) the statistical time delay for the appearance of a free electron, t_{sd}, which may be reduced to zero with the application of a UV source; (2) the streamer formation time, t_{sf}, which is inversely proportion to the electric field; (3) the channel heating time, t_{ch}, which is also inversely proportional to the electric field; and (4), the trigger pulse risetime, t_r.[1]
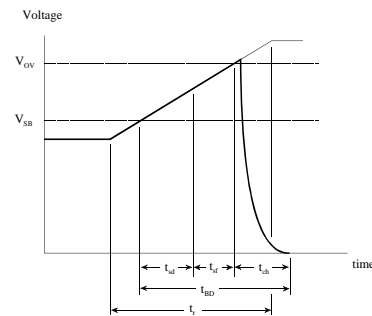

Figure 1. The gas breakdown process.

Reduction in jitter is primarily dependent on three parameters, UV illumination, a fast-rising trigger pulse (10 kV/ns), and a trigger voltage approximately equal in magnitude to the charging voltage. This paper focuses on the generation of the trigger pulse.
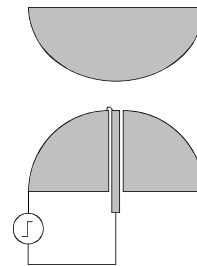

Figure 2. The trigatron spark gap

The trigatron gap of Figure 2 is a three electrode gap with the voltage held off between the anode and cathode. The third electrode, or the trigger pin, is placed within the cathode electrode such that initial closure of the spark gap begins with a breakdown between the trigger pin and the cathode. This initial breakdown generates a plasma in the high field region between the anode and cathode and ultimately leads to

the breakdown of the main gap. These systems are very easily fabricated and simply require a high voltage pulse for triggering. Unfortunately, these systems can result in high jitter values due to the fact that two breakdown events are required for switch closure.

The field distortion gap is shown Figure 3. In this configuration, a dc-biased wire is placed between the anode and cathode such that the electric field is not disturbed. A dc blocking capacitor may be used to isolate the high voltage from the trigger source. Gap closure is initiated when a negative pulse is delivered to the trigger wire and results in a highly distorted electric field between the main electrodes. The field distortion spark gap is ideal for low jitter applications, since only one breakdown is required for switch closure.
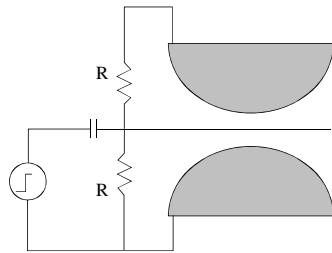

Figure 3. The field distortion spark gap with a blocking capacitor.

The field distortion gap may also be operated without the blocking-capacitor, as shown in Figure 4. The transmission line between the field distortion gap and the trigger switch is initially charges to the same potential as the trigger, or ½ the charge voltage.
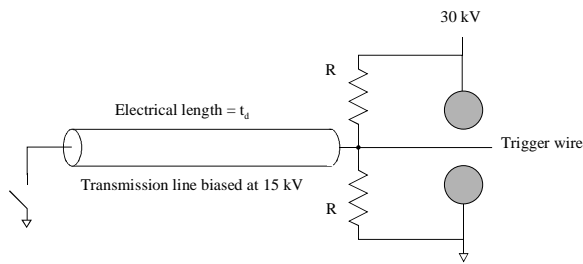

Figure 4. The field distortion spark gap with an initially charged trigger line.

Closure of the switch causes an inverted wave, equal in magnitude to ½ the charge voltage, to propagate toward the spark gap. Upon reaching the end of the trigger wire, the transient wave doubles to a potential of – ½ V, creating the highly distorted electric field. Note that the trigger switch must be able to hold off the bias voltage of the initially charged transmission line.

This transient behavior is simulated using PSpice, with the results shown in Figure 5. In this simulation, a 5 ns transmission line connects an ideal switch to the field distortion spark and is biased at 15 kV, or ½ the 30 kV charge voltage. The switch closure waveform illustrates the short circuit condition on the charged transmission line. The

transient wave propagates to the spark gap in a time defined by the electrical length of the transmission line, and the trigger wire is held at the new potential for a time defined by twice the electrical length of the transmission line, or 10 ns.
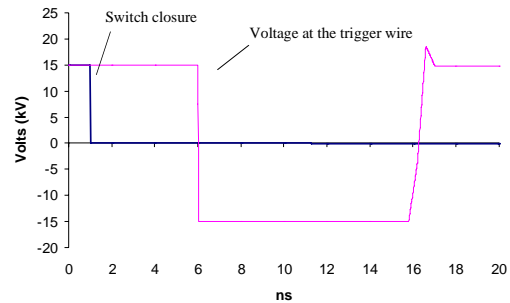

Figure 5. Simulation of the triggered field distortion spark gap.

Photoswitch Triggering Schemes

The photoswitch is a good candidate switch for providing a very high dV/dt required for low jitter triggering of the spark gap. Figure 6 illustrates the basic photoswitch configuration, in which a slab of semiconductor material is fitted with Ohmic contacts.
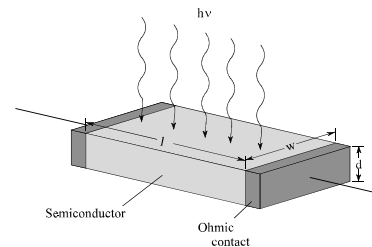

Figure 6. The basic photoswitch configuration.

In the linear regime of photoconductive switching, one electron-hole pair is created with each photon that is introduced into the bulk material. Unfortunately, for high powered applications, large and expensive lasers are required to generate a large number of carriers.

Alternatively, the nonlinear switch, in which only a few photons are required to generate many electron-hole pairs through an avalanching process, is ideal for triggering spark gaps, since these devices may be driven by inexpensive laser diodes. Furthermore, these devices have also shown high voltage (155 kV) and high current (7 kA) capabilities.[2] Unfortunately, the nonlinear photoswitch requires a large electric field (> 60 kV/cm) for the avalanche process to occur with low jitter, a trait that requires the pulse charging of the switch to avoid surface flashover.

The most obvious spark gap triggering with a photoswitch lies with the trigatron spark gap. This spark gap is ideal for the photoswitch since it may be

used without any modifications. Since the trigger pin of the trigatron is floating, the photoswitch circuit is effectively isolated from the high voltage of the main electrodes. Thus, the photoswitch operates in its natural state, one in which it is used to deliver a voltage pulse.

The field distortion spark gap holds the most promise for low jitter operation. A traditional photoswitch circuit may be used to trigger this gap as proposed by Figure 7. The blocking capacitor isolates the photoswitch circuit from the dc charge, and upon closure of the photoswitch, the trigger pulse propagates through the blocking capacitor to the trigger pin.
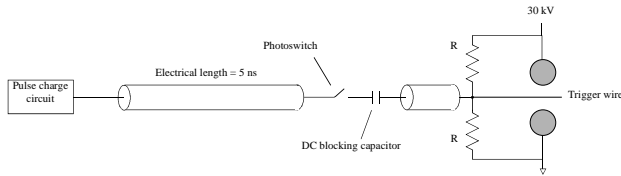

Figure 7. The field distortion gap triggered with a traditional nonlinear photoswitch.

The simulation results for this circuit are shown in Figure 8. As the voltage across the photoswitch collapses, the pulse propagates to the trigger wire. Note that the photoswitch must deliver at least twice the charge voltage of the spark gap to overcome the dc bias of the trigger wire.
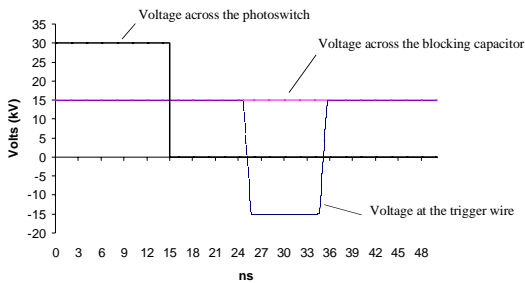

Figure 8. Simulation results for triggering a field distortion gap with a traditional photoswitch circuit.

While this configuration allows for the use of the traditional photoswitch circuit, the need for a high voltage capacitor makes it less desirable. Furthermore, the additional inductance associated with the relatively large capacitor slows the risetime of the voltage pulse, thus degrading the performance of the system through an increased jitter.

This simple configuration illustrates the fundamental problems faced with using the nonlinear photoswitch with the field distortion gap. The photoswitch must be pulsed-charged to a high electric field, one much greater than the surface flashover level. Conversely, the trigger pin of the field distortion gap must be biased with a dc voltage such that the electric field between the main electrodes is not disturbed. Unless a split power supply is used, a method that satisfies both conditions must be employed.

The transient pulsed-charged photoswitch scheme, shown in Figure 9, alleviates the need for the blocking capacitor as well as satisfying the necessary pulse-charging and dc biasing conditions. A "slow" switch (i.e. a thyratron or krytron), capable of holding off the dc bias voltage of the trigger wire, is added to the system as well as a bypass resistor. In the initial state, both transmission line sections are initially charged to the bias potential of the trigger pin, with the second transmission line being charged via the bypass resistor connected across the photoswitch. Thus, there is no potential difference across the photoswitch in the steady state condition.
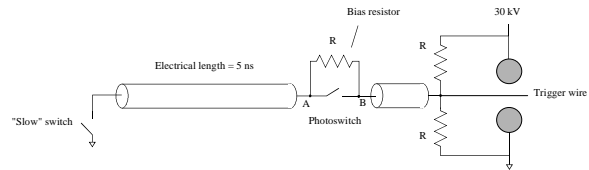

Figure 9. The transient pulsed-charged photoswitch configuration.

Upon closure of the "slow" switch, a transient wave propagates toward the photoswitch and doubles in magnitude upon arrival at the photoswitch, due to the open circuit, or non-conducting state of the photoswitch. While Node B is held to a positive voltage, the transient wave causes Node A to drop to a negative potential, creating a high electric field gradient across the photoswitch. Once the electric field reaches its peak magnitude, the photoswitch may be optically triggered.

The PSpice simulation of Figure 10 illustrates the pulse-charging of the photoswitch and the resulting pulse seen at the trigger wire.
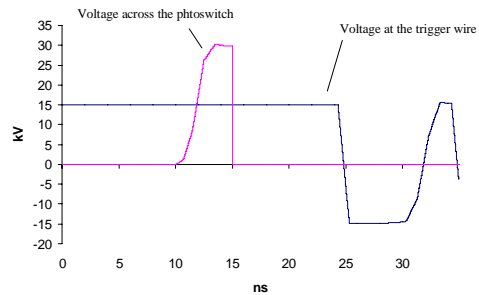

Figure 10. Simulation results of the transient-charge photoswitch trigger.

The limitations of the transient-charge photoswitch trigger are readily attributed to the nature of a transient wave event. In essence, the closure of the slow switch frees a wave that propagates the initially charge transmission line, and ultimately, rings between the "slow" switch and the photoswitch. Closure of the photoswitch must be done within a time defined by the

two-way transit time of the pulse-charge transmission line, such that the optical signal impinges on the material while the high electric field is present. This scenario is further complicated by the fact that the transient wave will be partitioned by the closure of the photoswitch.

For example, assume that the transient wave is 10 ns in length, and that the photoswitch closure occurs 5 ns into the pulse-charging event and remains conductive. Five nanoseconds of the transient wave will proceed directly to the trigger wire of the spark gap. Unfortunately, the remaining 5 ns will reflect off the photoswitch, prior to its closure, and propagate back to the closed "slow" switch. Upon reaching the "slow" switch, the pulse will invert and propagate through the photoswitch to the trigger wire of the spark gap. In this scenario, careful attention must be paid to the timing of the photoswitch to ensure that enough of the original transient wave reaches the field distortion gap to initiate gap closure.

The transient nature of the photoswitch may be greatly reduced by placing the "slow" switch between the photoswitch and the second transmission line, as shown in Figure 11, and effectively acts as a dc blocking element. The stray capacitance, between the "slow" switch and the photoswitch, is charged via the bias resistor such that the photoswitch once again does not have an electric field across it.

The second transmission line is charged with a initial negative charge. Note that any voltage level may be chosen for the initial charge since this method does not rely on transient effects to deliver an inverted pulse. However, a suitable switch must be used to hold off the voltage difference between the two transmission lines.
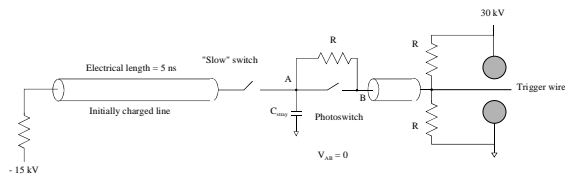

Figure 11. The waveless, pulsed-charged photoswitch.

Closure of the "slow" switch charges the stray capacitance to the negative potential of the second transmission line, effectively pulse charging the photoswitch since Node B remains at a positive charge.

The simulation results of the circuit are shown in Figure 12. The simulation reveals no transient reflections upon closure of the "slow" switch. And as a result, the photoswitch may be actuated at any time before surface flashover occurs. Note that the timing of the closure of the photoswitch is not dependent on the transient event generating the pulse-charging effect.
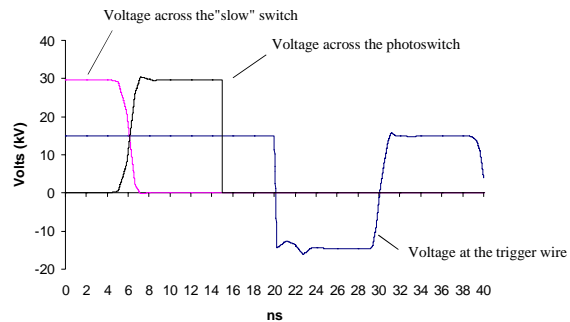

Figure 12. Simulation results of the waveless-charge photoswitch trigger.

Conclusion

Nonlinear photoconductive switches are very good candidates for triggering both the trigatron and the field distortion spark gaps, due to their ability to deliver very fast-rising, high voltage, low energy pulses, and show promise of limiting the jitter of these spark gaps to the sub-ns regime.

Special care must be taken to insure the proper operation of the switch. The switching configuration must allow for pulse charging of the switch. However, additional components, such as blocking capacitors can severely degrade the trigger performance. An additional concern lies in the longevity of the switch, due to the potential damage incurred by pulse reflections.

This paper has presented several candidate methods for triggering the field distortion gap with a nonlinear photoswitch switch and has predicted the performance through simulations. Future work will be aimed at experimentally demonstrating these methods.

References

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2. F.J. Zutavern, et al., *Properties of High Gain GaAs Switches for Pulsed Power Applications*, 11th IEEE International Pulsed Power Conference, Baltimore, 1997.

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