Development of transformer-based high-voltage trigger generator for pulsed power experiments

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1. Introduction

A high-voltage, fast-rise trigger generator based on a trigger transformer has been developed to conduct pulsed power experiments and high-energy-density (HED) research. The trigger generator generated a high voltage pulse of 50 kV, 2 µs rise time by connecting three trigger transformers in series. This generator operates by a TTL level (5V) trigger signal and makes a low-time jitter pulse, which is 1.9 ns. In this paper, the trigger generator circuit and operation principle are introduced, and its characteristic outputs for various loads and trigatron turn-on performance will be presented.

2. Methods and Results

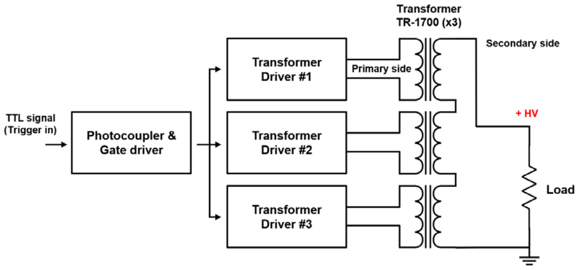

Fig 1. Schematics of the trigger generator

The generator consists of two parts: a transformer and a transformer driver, which drives the primary side of the transformer. As shown in Figure 1, the trigger transformer driver is paralleled so that inexpensive low-voltage IGBT can be used as the main switch of a transformer driver part. The secondary side of the trigger transformer is where the high-voltage pulses are generated, and it is connected in series so that a high voltage can be stacked and applied to a load.

2.1 Trigger generator

As the generator starts when it receives a TTL trigger signal, the waveform of the high-voltage pulse with respect to the trigger in time is important. Once a precisely evaluated output waveform is obtained, triggering is controllable with a delay generator. For example, reaching a specific voltage at a particular time is possible by giving a trigger signal before the voltage rise time.

The photocoupler's role is electrical isolation to protect the TTL signal generator (delay generator) by isolating the transformer driver side, where high voltage is applied, and the signal side, where the trigger signal is processed. A gate driver is connected to the photocoupler, and the IXDN609PI, an ultrafast MOSFET driver at Littlefuse Inc., is used as the gate driver. This gate driver has a low output impedance to handle relatively large currents, which can overcome stray capacitance of power devices like power MOSFET. [1] As a result, the gate driver enables the switching of the transformer driver to be faster and more reliable.

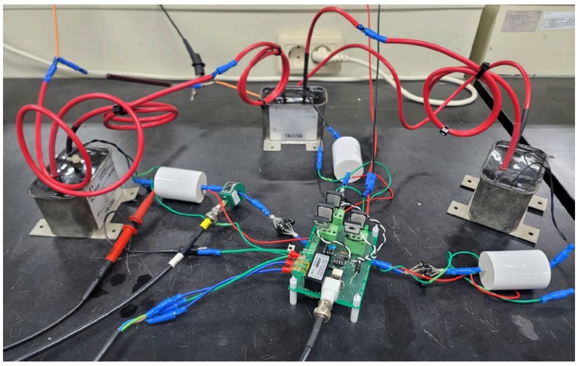

Fig 2. Entire picture of the trigger generator

2.2 Transformer driver

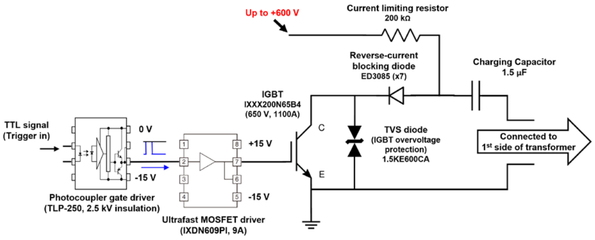

Fig 3. Schematics of the transformer driver

The transformer driver part is operated by gate driver output. The IGBT can hold up to 650V, and the pulsed maximum current is 1100 A for 1 ms. When the gate driver is in a low state, it applies -15 V to the gate of IGBT so that it can reliably turn off and prevent false turn-on. As the trigger signal is applied, the gate driver becomes a high state and applies + 15V to the gate of the IGBT so that it can turn on the IGBT. The collector side is positively charged, usually 100 – 600 V, but as IGBT turns on, collector voltage becomes collector-emitter saturation voltage, which is a few volts. As the capacitor is charged, another side of the capacitor becomes negatively charged state. Therefore, this negative voltage drives the primary side, and high voltage at the secondary side of the transformer can be induced. Considering that the transformer's output voltage is linear for the voltage applied to the primary side, the output voltage is proportional to the charging voltage.

As the IGBT is connected to the transformer, impulse voltage at the secondary side can drive the primary side, resulting in the malfunction of the IGBT or gate driver. Some protection components are used to protect the IGBT. The TVS diode protects the IGBT from overvoltage, and the reverse-current blocking diode prevents the current from flowing from the emitter to the collector. [2,3]

2.3 Rise time and time jitter

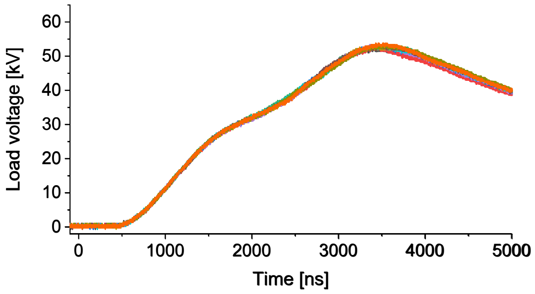

Fig 4. Overlapped load voltage for time jitter analysis.

In Figure 4, the TTL trigger signal is applied at t = 0 ns. The charging voltage is 300 V, and the load is open, so Figure 4 represents the electromotive force of the generator. About t = 500 ns, the output voltage rises to over 50 kV within 3 μs. Defining rise time as the time required to reach from 10% to 90% of its output, the rise time of this generator is 2.04 μs. Time jitter is evaluated for 20 shots, and the value is 1.9 ns. As the transformer driver comprises IGBT, it is reliable and operates in exact time.

2.4 Output voltage control

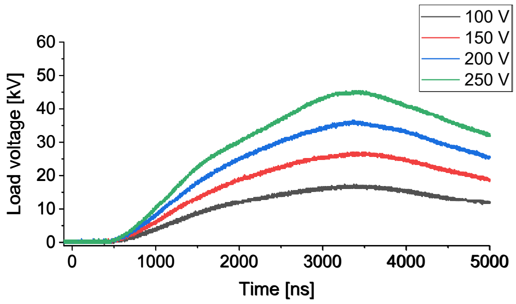

Fig 5. Load voltage by charging voltages.

As transformer output is proportional to the applied voltage at the primary side, it is possible to adjust the output voltage by varying the charging voltage. Figure 5 shows output voltages applied to an open load. It is possible to check that the output voltage is proportional to the charging voltage. As IGBT and TVS can hold up to 600V, the charging voltage can be increased to 600V, implying that the output voltage can be increased to 100 kV.

2.5 Output voltage for various impedance loads

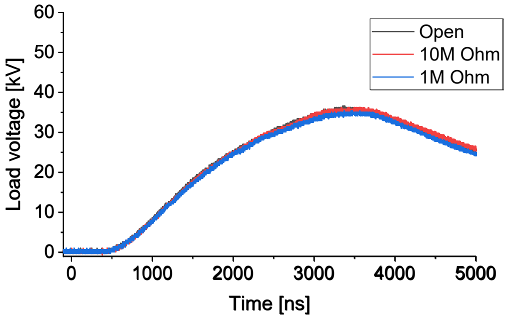

Fig 6. Load voltage for high impedance loads.

In Figure 6, the generator output voltage is applied to high-impedance loads while the charging voltage is 200 V. There is no significant difference in the waveform for open and megaohm loads, implying that the generator impedance is far less than megaohms.

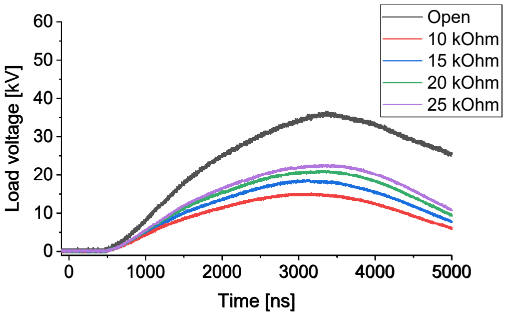

Fig 7. Load voltage for moderate loads.

In Figure 7, the generator output is applied to moderate-impedance loads while the charging voltage is 200 V. From this data, the generator impedance is 10.8

kΩ. To maximize energy transfer, the load impedance should be about 11 kΩ.

2.6 Trigatron turn-on

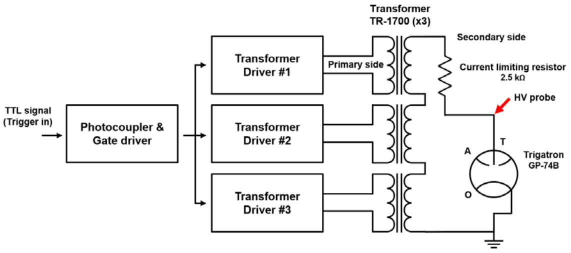

Fig 8. Experimental setup for trigatron turn-on test. The load is changed into trigatron.

The most representative applications of pulsed high-voltage generators are triggering other pulsed power devices. [4] The trigatron, most used for high-voltage switching, needs a high-voltage trigger of roughly 15 kV or higher. [5,6] At the trigatron turn-on experiment, GP-74B trigatron of Excelitas Tech. Corp., which requires at least 20 kV to turn on, is used. The most important thing for triggering the trigatron is to minimize turn-on time jitter so that it can be turned on at the desired time exactly.

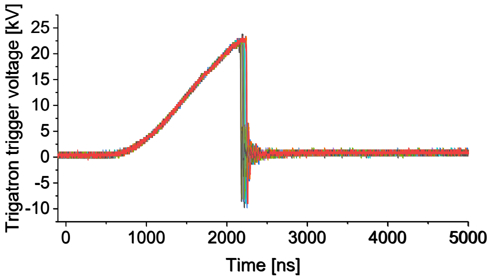

Fig 9. Overlapped trigatron trigger part voltage.

The TTL trigger signal is at t = 0 ns, and the charging voltage is 300 V. As can be seen in Figure 7, as soon as the trigatron is turned on, the trigger voltage rapidly drops to zero since the highly conductive plasma channel connects the O-A-T electrode. In Figure 7, 30 shots are used to evaluate the turn-on time. The average turn-on time with respect to the trigger signal is 2206 ns, and the turn-on time jitter is 24 ns.

3. Conclusions

The transformer-based high-voltage trigger generator is developed. Its output voltage is about 50 kV when the charging voltage is 300 V. Considering that the charging voltage can be increased to 600 V, the output voltage can be increased to 100 kV. This high voltage is acquired by connecting three transformers in series. If more transformers are connected in series, the output voltage can be higher and faster. This implies a good extendibility of transformer-based trigger generators. The rise time of the generator is 2.04 µs, and the time jitter is 1.9 ns. For GP-74B trigatron, the average turn-on time is 2206 ns, and the time jitter is revealed as 24 ns.

Acknowledgements

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