Design and Commision of Solid State Switch Driver in SLAC Subbooster Modulator

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***Abstract*— The LINAC sub-booster modulator is a pulsed power supply to provide a 30kV pulse to drive a klystron in SLAC LINAC. It has utilized vacuum tetrode as pulse switch for more than 60 years. With the vacuum tetrode availability becoming less and its cost surging, a natural choice is to use solid state switch in this pulsed power modulator. To commission solid state switch in LINAC sub-booster modulator, a driver board is designed to drive a BEHLKE HTS-LC2 series MOSFET based switches. The design concept and some concerns in design will be presented. The driver board is universal for all HTS-LC2 series switches because they share the same driver signals and connections. After the driver is commissioned, two AI systems are introduced to design one core part of the driver, the results are presented here. During the commission of the driver board in the LINAC sub-booster modulators, some problems happened and were addressed.**

Keywords—Vacuum Switch; Solid State Switch Driver; AI Circuit Design, Modulator

I. INTRODUCTION

The sub-booster modulator provides a 5.1μS high-power pulse to the initial microwave amplifier (klystron). The sub-booster klystron and modulator combination is to amplify microwaves at 2856 MHz from 60mW to 60kW to seed the next stage klystron/modulator combination in SLAC LINAC system [1, 2].

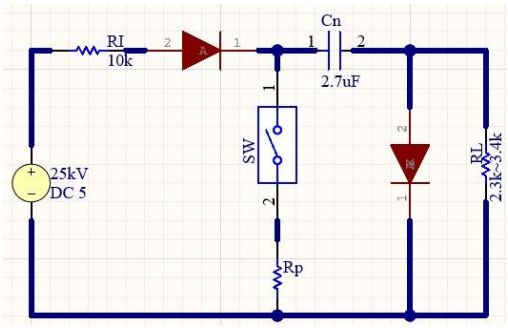

Fig. 1. Simplified Sub-booster modulator circuit

II. DRIVER DESIGN

Figure 1 is a simplified sub-booster modulator circuit. Y448 pair tubes were used as the switching devices. BEHLKE HTS-LC2 series solid-state switches are tested [2] and HTS 701-10-LC2 and HTS 901-10-LC2 are selected to commission in SLAC sub-booster modulators. HTS 701 and 901 switches need a TTL trigger pulse to drive the switches with a voltage from 3V to 6V. The trigger pulse width will determine the switch close time. Once the trigger pulse disappears, the solid-state switch will be open. An auxiliary DC power supply is required with 0.6A capability is required to drive the solid-state switch. The switch fault signal is provided by the switch in TTL [3]. In SLAC sub-booster modulator, the timing trigger is a 40V pulse at 120Hz. The primary part of the driver board is to convert 40V pulse to 10V pulse with a pulse transformer. 74AC14 inverter with Schmitt trigger input is used to capture the ring edge of the 10V pulse. After that, a monostable multivibrator MC14528 is used to generate a variable width 10V pulse. A high current FET driver UC3710 is used to provide 5V trigger pulse to BEHLKE HTS-LC2 solid state switch. UC3710 is fed by a 10V pulse from an AND/OR gate after MC14528. This part is a core part of solid-state switch driver circuit, illustrated in Figure 2.

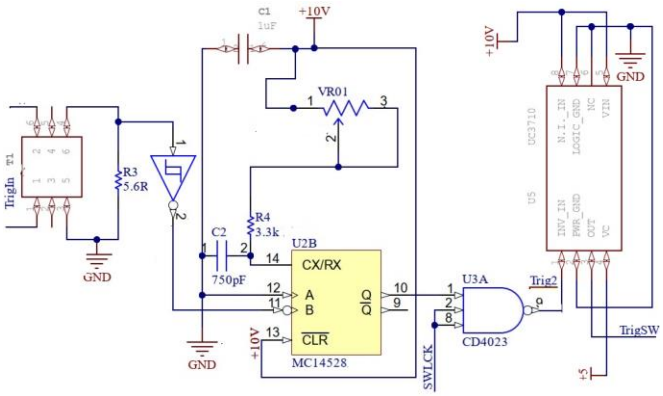

Fig.2. Core Part of Solid-State Switch Driver Circuit

Another part of the circuit is to incorporate the 5V switch fault signal to disable the solid-state switch by sending a TTL low level to inhibit the solid-state switch and lock the trigger signal. These functions are mainly realized by digital logic. Another thing is that we use a 24VDC relay to disable the whole sub-booster modulator high voltage once the solid-state switch is disabled by any reasons. This is a part of personnels and equipment protection program. The 24VDC relay is operated by 10VDC.

The AI systems are introduced to design the core part of the circuits. ChatGPT and xAI free versions are used to do the design. Both systems can select right ICs, such as 555 timer, to

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finish the job, although sometimes AI cannot finish some trivial connections. AI systems are helpful in initial design step and will develop more capabilities.

III. Commission of the Driver Board

The solid state switch boards with HTS 701 and 901 switches have been commissioned in several sub-booster modulator stations at SLAC. The driver board is working very well while the HTS solid state switch is not hooked up. All signals are smooth without too much noises. With the solid state switch connected, two signals: 10V trigger pulse to UC3710 and 5V trigger from UC3710 to the solid state switch, are monitored. +5V DC to the solid state switch is also monitored.

Fig. 3 shows waveforms from a driver board without connecting a switch.

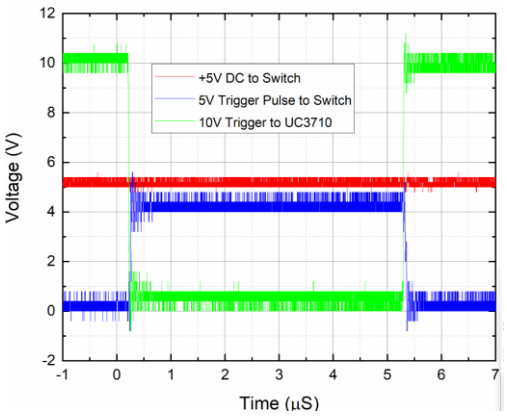


Fig. 3: Waveforms without Solid State Switch Connected

Fig. 4 shows the waveforms from a driver board with a HTS 901-10-LC2 connected without 22.5kV applied. The switch starts working with actual high voltage.

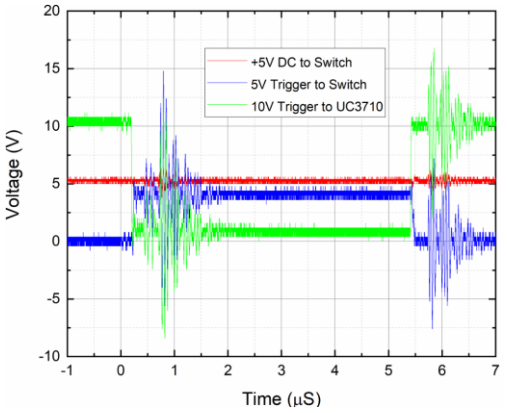


Fig. 4. Waveforms with Sloid State Switch working zero high voltage

Fig. 5 shows the waveforms from a driver board with 23kV applied. The 23kV pulse are generated by the solid state switch functioning.

Comparing Fig. 3, 4 and 5, it can be seen that noises will be coupled into the driver board while the solid state switch acts open and close. The noises are not coupled primary through DC power supply. The noises in +5VDC has limited noises comparing with the trigger signals, which can be seen in Fig. 4 and 5. General noises level with applied 22.5kV in all monitored signals gets much bigger than without high voltage. Fig. 6 shows the trigger signal to switch, the high voltage pulse and the microwave amplitude generated by the klystron with 22.5kV high voltage pulse.

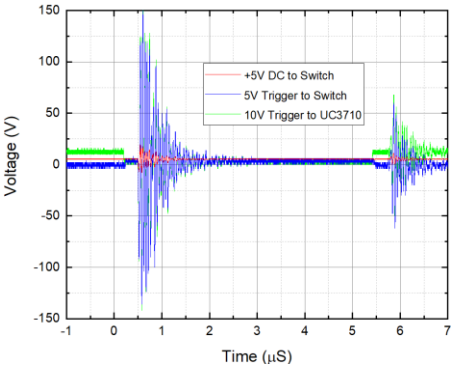
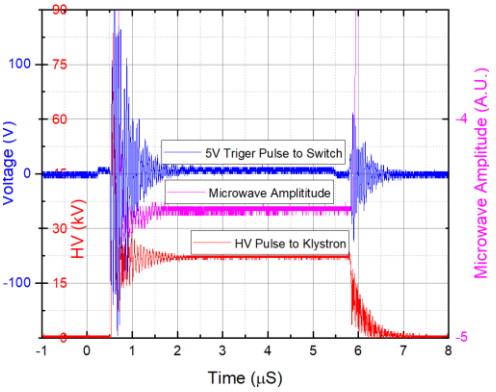


Fig. 5. Waveforms with Solid State Switch working on 22.5kV



In Fig. 4, 5 and 6, we can see that the solid-state switch will act 0.25μS later than the trigger signal edges. Every action will generate many noises in the circuit of the driver board. The solid state switch and the driver board work pretty well in 24/7 continuously mode in SLAC LINAC gallery.

IV. Summary

A driver board is developed and commissioned to drive the HTS 701/901-10-LC2 solid-state switch in SLAC sub-booster modulators. Although many noises are generated in the driver boards while the solid-state switch acting, the system works pretty stable 24 hours per day and 7 days one week in SLAC. One HTS 701-10-LC2 switch has been commissioned in one sub-booster modulator since Feb. 9th, 2022 and the other HTS 901-10-LC2 has been commissioned in another sub-booster modulator since April 24th, 2024. The life-time are still extending further.

[1] R. B. Neal, et al, "The Stanford Two-Mile Accelerator", W. A. Benjamin, Inc., pp. 411–465, 1968.

[2] X. Chen and J. De Lamare, "SLAC LINAC Sub-Booster Modulator Upgrade with Solid State Switch," 2022 IEEE International Power Modulator and High Voltage Conference (IPMHVC), Knoxville, TN, USA, 2022, pp. 129-132, doi: 10.1109/IPMHVC51093.2022.10099405.

[3] Fast High Voltage Transistor Switches, https://www.behlke.com/pdf/901-10-lc2.pdf