FIBER OPTIC OSCILLOSCOPE PROBE*

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Abstract

In the recent development of high voltage solid state pulsed power systems, the ability to monitor low voltage signals in a high voltage environment has been a problem. The amplitude of any ground bounce from the high voltage pulse can make the interpretation of low voltage diagnostic signals difficult with industry standard probes.

The paper explains the development of a fiber optic voltage probe for the oscilloscope. Included are explanations of the probe's design, fabrication, limitations, and performance when compared with standard probes in a high voltage pulsed power environment.

I. INTRODUCTION

The Beam Research Program at Lawrence Livermore National Laboratory has been developing a Solid State Kicker Pulser for DARHT-2. The pulser is a 20kV induction adder circuit with rise and fall times of less than 10ns. The pulser is designed around an array of MOSFETs. A critical diagnostic point for monitoring and troubleshooting this pulser is the gate of the MOSFET. In this confined high voltage pulse environment, noise and ground bounce become an issue when attempting to monitor low level gate pulses (5v – 15v). A method of monitoring the gate pulse while the high voltage pulse is being switched was needed. The development of a fiber optic oscilloscope probe was necessary to provide a way to conveniently monitor any gate pulse without hardwiring an optical transmitter into the circuit.

II. DESIGN

This probe was designed specifically for looking at the voltage waveform of the gate of a MOSFET. With the complete understanding of its design and limitations, it could be used for other purposes. (Figure 1).

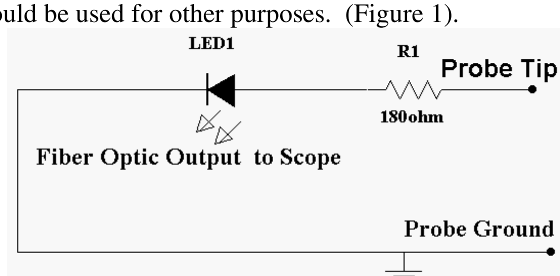

Figure 1. Circuit

The biggest factor in the performance of this probe is the value chosen for the series resistor (Figure 1. R1). With the circuit inductance dictated by the physical design of the probe, the resistance must remain large enough to achieve the rise and fall times desired. Keeping the resistance high enough to achieve these fast rise and fall times also limits the total current through the fiber optic transmitter. Limitations caused by this current level will be addressed later. This probe was designed to measure a specific pulse (15V, 20A) and to have a fast rise and fall time. By varying the value of R1 the probe can be customized for specific applications.

III. FABRICATION

The optical probe was fabricated from a damaged Tektronix P6139A probe and modified to accept a fiber optic transmitter and a current limiting resistor (Figure 2-6). While many probes or transmitters may be used, the transmitter chosen for this probe was a PD-LD SLED. Part #. PLD-S08-191-080-PH2. By terminating the end of the fiber onto an ST connector, it can be inserted into an optic/electrical converter and then to an oscilloscope. These optic/electrical converters are available throughout the industry for minimal cost. For this probe, a series resistor of 180• was chosen.

A. Low Inductance Fabrication Procedure

1) Start with parts from a Tek. P6139A probe. Figure 2

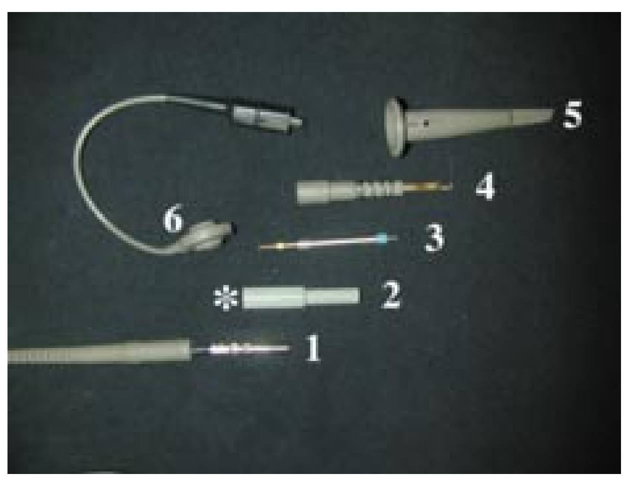

Figure 2. Parts from a Tek. P6139A probe. Refer to numbered parts for assembly procedure.

2) Drill out half of part #2 (*) to 13/64"
3) File the outside of part #2 (*) to fit into part #4

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14. ABSTRACT

In the recent development of high voltage solid state pulsed power systems, the ability to monitor low voltage signals in a high voltage environment has been a problem. The amplitude of any ground bounce from the high voltage pulse can make the interpretation of low voltage diagnostic signals difficult with industry standard probes. The paper explains the development of a fiber optic voltage probe for the oscilloscope. Included are explanations of the probes design, fabrication, limitations, and performance when compared with standard probes in a high voltage pulsed power environment.

15. SUBJECT TERMS

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4) Drill out part #3 to 7/64" leaving only the metal.
5) Drill a small hole in part #4. (Figure 3)
6) Remove plastic from part #4 to expose the probe tip. Your resistor must fit between the drilled hole and newly exposed probe tip. (Figure 4)
7) Run Fiber through parts 3, 2 (* end first), 6, 1, and the strain relief in that order.
8) Remove case lead and small strain relief from transmitter.
9) Insulate anode lead of transmitter and fold back cathode lead to touch the case.
10) Connect part #3 and cathode to transmitter body with silver epoxy. (Figure 5)
11) Slide part#2 over transmitter and feed the transmitter and part #2 into part #4 so that the anode protrudes through the hole and makes contact with the series resistor. (Figure 6)
12) Use silver epoxy to make contact from anode to resistor and resistor to probe lead. The epoxy can also be used to secure part #2 to part #4. Make sure to maintain contact between part #3 and the transmitter body while assembling.
13) After epoxy dries thread part #3 and Part #1 together, insert part #4 into part #5, attach strain relief.

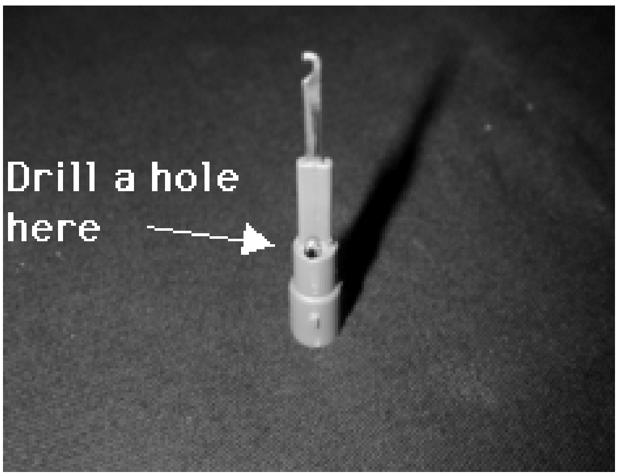

Figure 3. Create a hole for the transmitter anode.

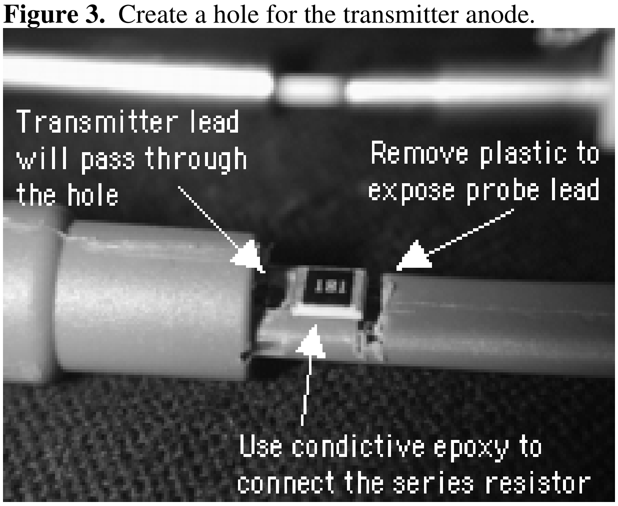

Figure 4. Remove the plastic to expose the probe tip conductor. Silver (conductive) epoxy will be used later.

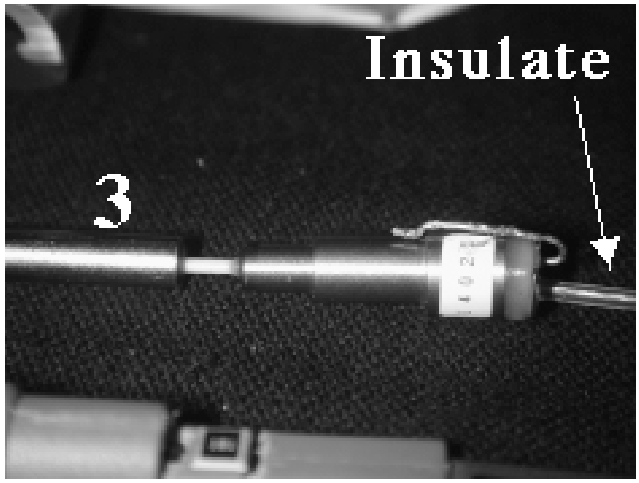

Figure 5. Connect part #3 and the transmitter body with silver epoxy.

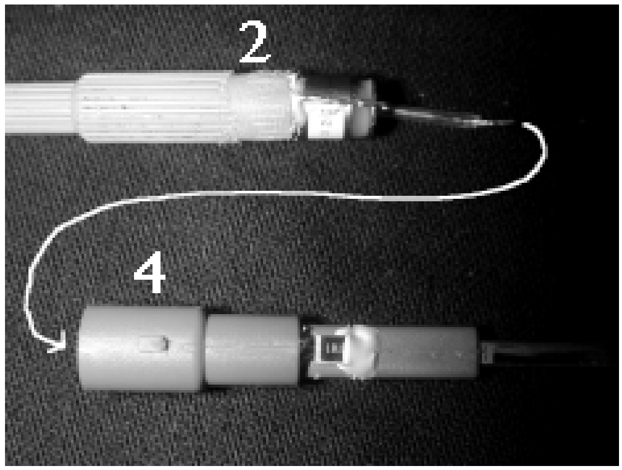

Figure 6. Allow the transmitter and resistor connections to dry before installing part #2 into part #4.

The key in the fabrication is to keep the inductance as low as possible. By modifying an old probe you can take advantage of low inductance hardware, use the flexibility already designed into the old probe, and save the cost of custom machining.

IV. LIMITATIONS

This probe has the following limitations and for these reasons may not be suitable for use in all applications.

A. Pulse Width

The Fiber Optic Transmitter (Figure 1. LED1) requires a forward bias to turn it on. This will cause a propagation delay for the rise time. Likewise, during the fall time once the signal falls below this threshold the signal will turn off. The total pulse width measured by this probe will be less then the actual pulse width being measured.

B. Amplitude

The amplitude of the measured pulse is a measurement of optical power (µW). This optical power is the result of many factors. Bends in the optical fiber, coupling at connections, and most important the amount of current flowing through the transmitter. Variations in these factors make the probe difficult to calibrate to a specific µW/volt, but still allow for an accurate measurement of the waveshape.

C. Current Draw

This probe is not a high impedance probe. Current must pass through the transmitter in order for it to work. This probe will draw current from and affect the circuit being monitored.

D. Nonlinearity

The transmitter selected for this probe maintains linearity at higher currents but lacks it at lower levels (Figure 7.)

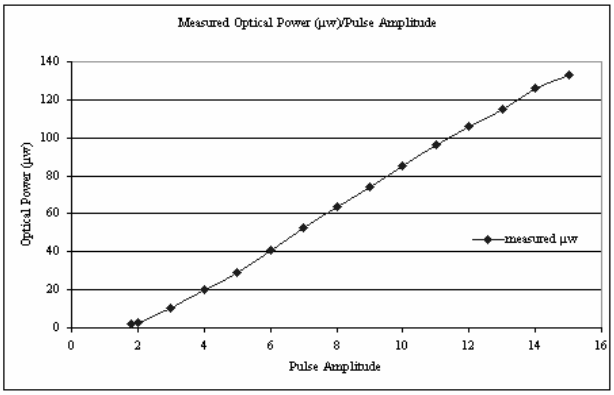

Figure 7. Notice knee at lower amplitudes

E. Sensitivity to DC Measurement

This probe works by drawing current from the circuit being tested. On a DC rail the probe will provide a path for continuous current to ground. This will work as a probe but precautions need to be taken to insure that the maximum power ratings for both the transmitter and the series resistor are not exceeded. The forward bias voltage of the transmitter should also be taken into account when attempting to measure a DC rail.

F. No Negative Measurement Capabilities

The transmitter is a diode and only allows current to pass in the forward direction. Figure 11.

V. PERFORMANCE

This probe, in some applications, has limitations when compared with probes currently available in the industry. However, for the application it was designed it performs very well. This probe is designed to observe a 15V, 20A, gate pulse on a MOSFET switching 600-700 volts. The test circuit for Figures 8-10 consists of a pulse generator or arbitrary waveform generator connected directly to an oscilloscope. The signal is directly coupled by coaxial cable into Ch2 and internally terminated into 50•. A tee is installed at the oscilloscope and serves as a monitor point for the optical probe.

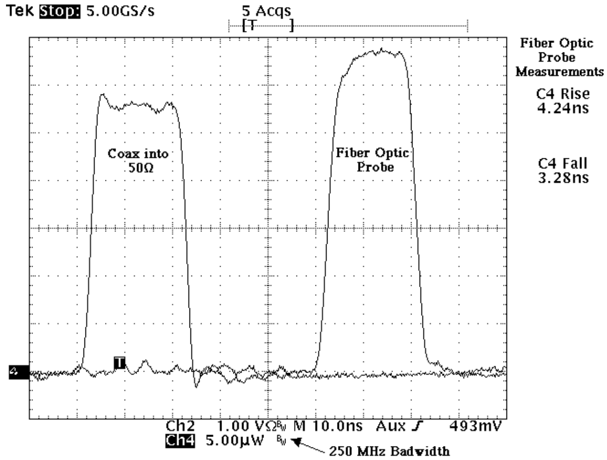

Figure 8. 6V 20ns pulse. 10ns/div
Ch2: 1V/div CH4: 5µw/div

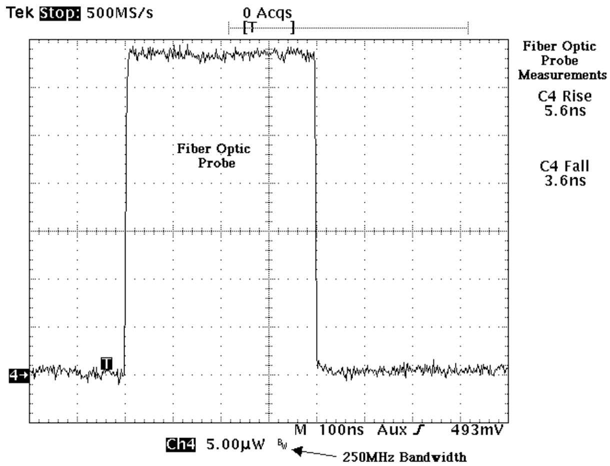

Figure 9. 6V, 400ns pulse. 100ns/div
Ch4: 5µW/div

The Fiber Optic probe measures long pulses without problems (Figure 9). The best way to use this probe is to calibrate it against a known waveform before the high voltage switching is performed. By adjusting the scale (µW/div) to match the waveform of a standard probe the Fiber Optic probe can provide data which translates to a volts/div (Figure10).

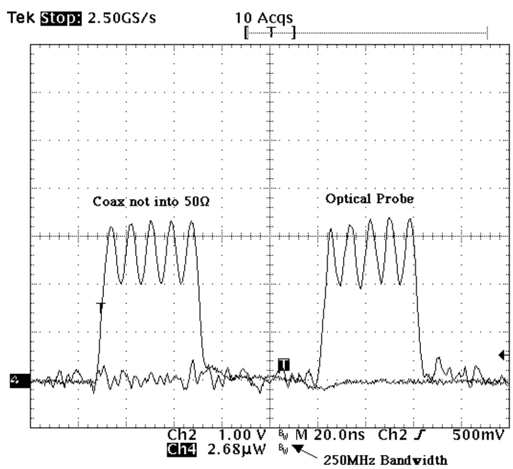

Figure 10. 20ns/div.

Figure 11 is a measurement of the waveform this probe was designed to monitor. No voltage is being switched through the MOSFET. This picture also demonstrates the probe's inability to monitor negative voltage. Figure 12 shows both the Fiber Optic probe and the Tek. P6139A probe measuring a single gate pulse while the MOSFET is switching 625V. In this high voltage environment you can see the benefits of the Fiber Optic probe over other probes. The Tek. P6139A is picking up induced noise from the High Voltage Pulser.

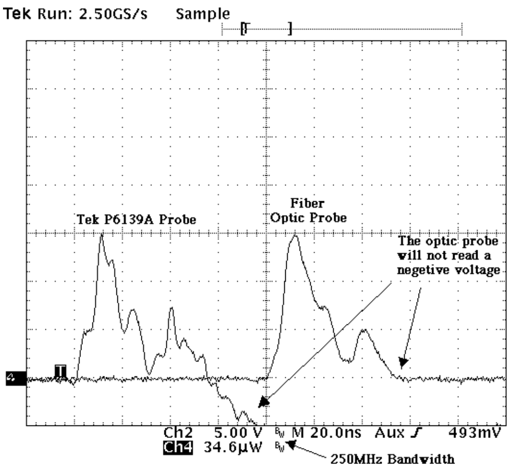

Figure 11. 15V, 30ns, Gate pulse. 20ns/div.
Ch2: Tek. P6139A probe, 5V/div.
Ch4: Fiber Optic probe, 34.6μW/div.

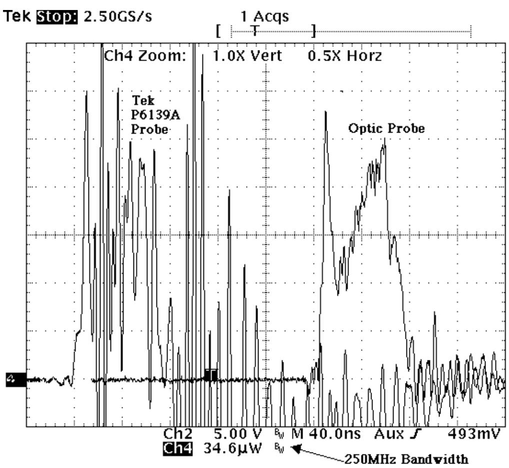

Figure 12. 15V, 70ns, Gate pulse. 40ns/div.
Ch2: Tek. P6139A probe, 5V/div.
Ch4: Fiber Optic probe, 34.6μW/div.

By monitoring this gate pulse with the Fiber Optic probe it is much easier to determine how long and when the MOSFET was commanded to switch.

VI. SUMMARY

A fiber optic probe can be fabricated to monitor low voltage signals in a high voltage environment. With proper component selection a fiber optic probe will produce useful measurements not easily obtainable by other probes. Consideration should be given to the waveforms to be monitored while in the early stages of the probe's design.

VII. REFERENCES

R. Saethre, H. Kirbie, B. Hickman, B. Lee, C. Ollis, "Optical control, diagnostic and power supply system for a solid state induction modulator", in Proc. 11th IEEE Int. Pulsed Power Conference, 1997, pp.1264-1269 Vol. 2.