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).

A. Low Inductance Fabrication Procedure

1) Start with parts from a Tek. P6139A probe.
2) Drill out half of part #2 (*) to 13/64”
3) File the outside of part #2 (*) to fit into part #4

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.

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### FIBER OPTIC OSCILLOSCOPE PROBE

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.
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.

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.)

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 50Ω. A tee is installed at the oscilloscope and serves as a monitor point for the optical probe.
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.

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