FIBER-OPTIC SYSTEMS AT THE EXPLOSIVE PULSED POWER TEST FACILITY AT AFRL

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Abstract

The Air Force Research Laboratory (AFRL) located on Kirtland Air Force Base performs explosive pulsed power experiments [1] - [3]. The large separation distances between the related subsystems of these shots increase the likelihood of inadvertent multiple electrical ground connections. This paper describes some of the fiber-optic devices routinely used during our explosive power tests to mitigate the problems associated with ground loops.

I. INTRODUCTION

Fiber optic technology has made substantial increases in capability as well as significant decreases in cost in recent years. Most fiber-optic equipment sold today is intended for computer and telephone system application. Though not optimal for use in pulsed power diagnostics and control systems, some can be adapted and, with the design and fabrication of special purpose components, can be applied to meet critical isolation needs in the field. Fiber-optic applications described here include trigger transmitters and receivers; multiplexed controls for instruments and high voltage power supplies; and Faraday probes for monitoring large amplitude currents. Some off-the-shelf commercial items worthy of particular note will be mentioned along the way.

II. FIBER-OPTIC TRIGGER TRANSMITTERS & RECEIVERS

Fiber optic triggering facilitates electrical isolation desirable for many high-power pulsed power experiments. The schematic for a simple and robust fiber-optic trigger-receiver design is shown in Fig. 1. For TTL applications, the circuits in Fig. 2 work for pulse widths as short as 100 nanoseconds [4].

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14. ABSTRACT

The Air Force Research Laboratory (AFRL) located on Kirtland Air Force Base performs explosive pulsed power experiments [1] - [3]. The large separation distances between the related subsystems of these shots increase the likelihood of inadvertent multiple electrical ground connections. This paper describes some of the fiber-optic devices routinely used during our explosive power tests to mitigate the problems associated with ground loops.

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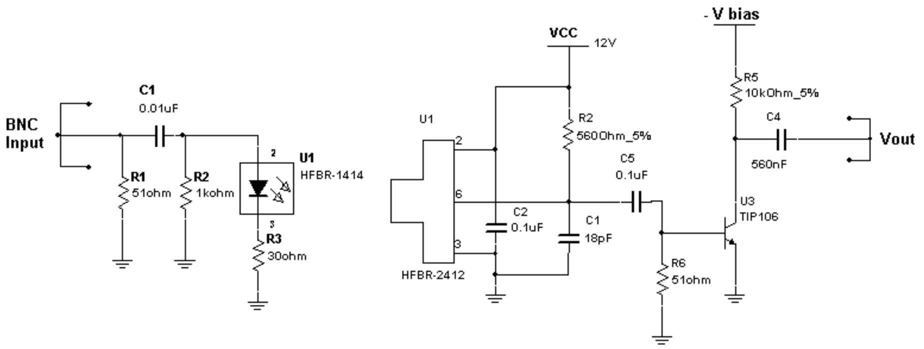

Figure 1. Fiber-optic trigger / receiver circuit.

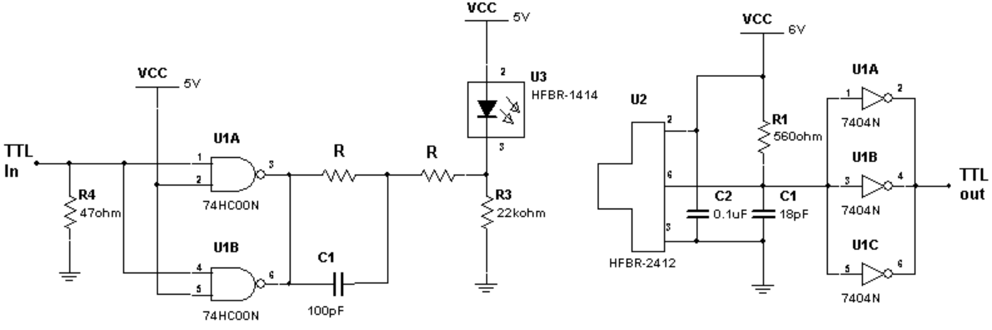

Figure 2. TTL fiber-optic trigger / receiver circuit.

III. MULTIPLEXERS FOR INSTRUMENT CONTROL

Fiber-optic multiplexer transmitter/ receiver systems allow the user to remotely operate various instruments and equipment. In these systems, an N channel multiplexer fiber-optically transmits the present state of N electrical switches and the corresponding fiber-optic receiver then duplicates the state for those N switches. We have multiplexed the operation of 1) high speed framing cameras, 2) power disconnect devices to turn off equipment or switch to internal battery, and 3) high voltage power supplies. We have had great success with the eight channel transmitter-receiver systems from International Fiber Systems, Inc. (# DT 1810 / DR 1810). They communicate using two ST multi-mode fibers, have an optical budget of 14 dB, an operating temperature range of -40 deg C to +70 deg C and have been found to extremely reliable in our field tests.

IV. FIBER-OPTIC HIGH VOLTAGE POWER SUPPLY

Explosive pulsed power experiments require that explosive devices be electrically connected to high voltage before detonation. To minimize the likelihood of a premature detonation of the explosive caused by the pulsed high voltage arcing to ground, we allow the detonator electronics to electrically "float" to the high voltage. We have accomplished this by designing a battery-powered, 10 kV power supply controlled by a fiber-optic receiver, and a companion fiber-optic transmitter, remotely controlled by the user. The user dials in a desired charge voltage and actuates the start-charge switch; the remote receiver charges and maintains the detonator electronics to this desired voltage level. The actual charge voltage information is also sent back to the user panel for display. For compactness, the fiber-optic control also provides the electrical initiation trigger to the detonator.

V. FARADAY PROBE

We have implemented a Faraday probe current diagnostic for our explosive pulse power experiments. The Faraday effect [5, 6] enables large amplitude current measurements with high accuracy, and the probe can be implemented fiber-optically to provide electrical isolation. We have adapted a technique for fielding the Faraday probe first developed by Los Alamos National Laboratory [7].

During the implementation of our Faraday probe, however, we noticed that both the probe output signals maximum and minimum envelope was non-uniform. This non-uniform behavior of the max/min envelope seemed to be consistent between the two output signals. Assuming that this non-uniformity is upstream of the beam-splitter we have developed a numerical method to remove its common effect. If we align the two probe polarization filters A & B at angles of θ & θ + 45° with respect to the polarized plane of the incident light, the resulting two photo-detector output signals are given by: $V_{\det A} = K_a E_o{}^2 \cos^2(\theta)$ & $V_{\det B} = K_b E_o{}^2 \cos^2(\theta + 45)$. K_a & K_b are the photo-detectors sensitivities.

Using the two trigonometric relationships

$$\cos^2(\theta) = \frac{1}{2} + \frac{1}{2}\cos(2\theta) \quad \&$$

$$\cos(2\theta + 90^\circ) = -\sin(2\theta)$$

We obtain:

$$V_{\det A} = \frac{K_A E_o^2}{2}(1 + \cos(2\theta)) \ \&$$

$$V_{\det B} = \frac{K_B E_o^2}{2}(1 + \cos(2\theta + 90^\circ))$$

Solving for cos(2θ) and sin(2θ) we get:

$$\cos(2\theta) = \left(\frac{V_{\det A} - \frac{K_A E_o^2}{2}}{\frac{K_A E_o^2}{2}}\right) = \text{Norm } V_{\det A} \ \&$$

$$\sin(2\theta) = \left(\frac{V_{\det B} - \frac{K_B E_o^2}{2}}{\frac{-K_B E_o^2}{2}}\right) = \text{Norm } V_{\det B}$$

We also know that:

$$2\theta = \arctan\left(\frac{\sin 2\theta}{\cos 2\theta}\right).$$

This allows us to write:

$$2\theta = \arctan\left(\frac{Norm\,V_{\det B}}{Norm\,V_{\det A}}\right)$$

The current, I, can be given by:

$$I = \frac{\theta}{VN} \quad \text{(MA)}$$

Substituting 2θ we obtain:

$$I = \left(\frac{1}{2VN}\right)\arctan\left(\frac{Norm V_{\det B}}{Norm\,V_{\det A}}\right) \quad \text{(MA)}$$

This two photo-detector analysis approach works well if the system has both photo-detector signals. If a problem with the diagnostic develops and only a single photo-detector signal is usable, the above analysis cannot be done and other techniques need to be employed.

In figure 3a we present an overlay of the two photo-detector signal outputs from a Faraday probe measurement taken during an explosive shot. Figure 3b is the same plot as figure 3a except the time scale has been changed to provide a better view of the faster fringes produced from the probe. In figure 4 we present the calculated current using this two photo-detector numerical technique:

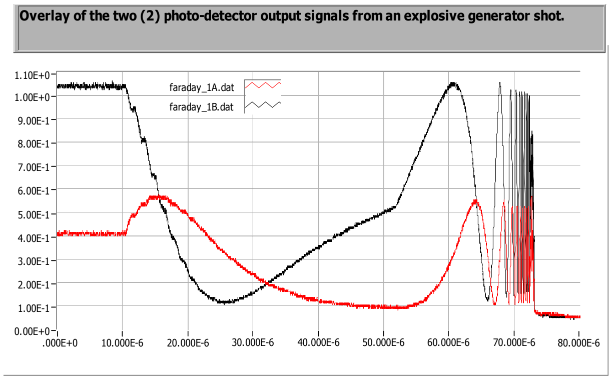

Figure 3a. Signal outputs for a 2 channel Faraday probe.

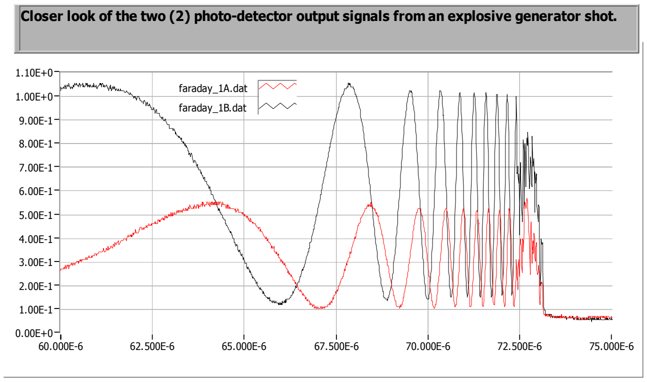

Figure 3b. Zoomed in look of signals shown in 3a.

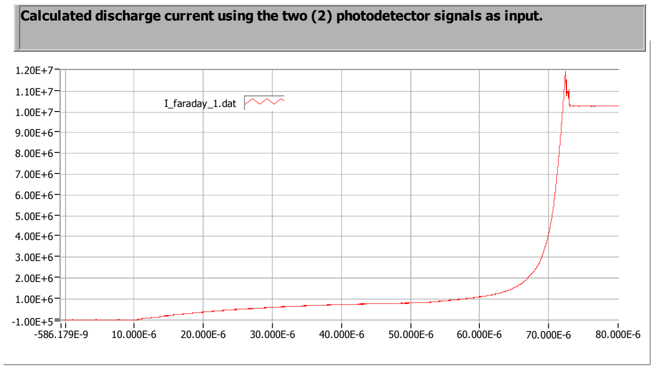

Figure 4. Calculated current using the 2 photo-detector channel signals.

Both photo-detectors signals get very noisy around 72 μs. We believe that the fibers are shocked and their response becomes non-linear; as the fibers are adversely sensitive to shock they should be mounted accordingly.

VI. SUMMARY

Fiber-optics provide many advantages to the researcher and this paper has touched on their implementation in various manners for triggering, instrument control, high-voltage power supplies, and as a high-current sensing diagnostic. We presented some practical approaches for fiber-optic triggering and examined why and how we implement more sophisticated devices. The use of fibers has resolved electrical ground loop problems and due to better manufacturing processes the fibers are mechanically robust allowing their installation in experiments to be less problematic.

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