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AUTHOR(S):

Jerome D. Paul, C. Rodger Hall, Sarl Mozzano, Stephen Grant

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Development of a Passive Electrical-to-Optical Pulse Converter for the Production of High Resolution Fiducial Signals

Jerome D. Paul, C. Rodger Hall

Los Alamos National Laboratory

Los Alamos, NM

and

Sarl Mozzano, Stephen Grant

Allied Signal, Federal Manuf. and Technology

Kansas City, MO

1. ABSTRACT

The analysis of many high explosives (HE) involves the use of rotating-mirror cameras and high speed film. Fiducial timing spots are made on the film to provide temporal reference to the experimenter during subsequent evaluation. The writing speed of the "streak" camera is 10 millimeters per microsecond, thus, the optical fiducial pulse width must be on the order of tens of nanoseconds to generate a useful spot size. For this application, a useful spot size corresponds to a width of 200-300 micrometers. Present systems employ light-emitting diodes for this task, mounting them at the focal point of the camera. However, the size and clarity of the current timing spot on the film is less than optimum. Furthermore, experiments involving high explosives require the isolation of the electronic instrumentation from the experimental hardware and passive operation is always preferred if not required. This is due to safety requirements as well as instrumentation ground loop and EMP concerns. Another restriction is the diminished sensitivity of the high-speed film to wavelengths above 600 nanometers, which narrows the field of possible optical sources considerably. A passive, fiber-coupled system based upon a 635 nanometer laser diode has been developed and tested. The development process, final design and test results are presented and the improved signal resolution is compared with current technology.

**Key Words: Fiber-coupled Laser Diode, Optical Isolation,
Saturable-Core Transformer, Low-Jitter Timing,
High-resolution Fiducial, Streak Cameras**

2. INTRODUCTION

One of the most valuable tools available in the analysis of "energetic experiments" such as explosive reactions is that of the rotating mirror "streak" camera. Through precise timing correlation between mirror rotation and the explosive reaction, a great deal of spatial and reaction rate information can be recorded on the film. The Cordin Model #136, shown schematically in Figure 1, is one camera currently used for this purpose. A slit-plate is installed at the focal plane of the camera to buffer the exposure from the experiment. This camera is part of a sophisticated Firing Chamber which employs a variety of diagnostics to analyze high explosive reactions. Timing and firing are operator controlled while data acquisition and reduction are accomplished through a PC platform.

Figure 1. Cordin Rotating Mirror Streak Camera (side view)

The camera timing reference signal is referred to as the "fiducial". The fiducial signal for the camera consists of a computer-generated sequence of optical pulses which provides the experimenter with temporal reference data and allows the experimenter to determine the beginning and end of the data. Figure 2 shows the sequential pulse stream. As previously noted, the camera writing speed is 10 millimeters per microsecond. In order to achieve reasonable resolution at these writing speeds, the optical pulses are 20 nanoseconds wide with a period of 500 nanoseconds.

Figure 2. Computer-generated Fiducial Signal

This fiducial requirement was met by using the circuit¹ in Figure 3. It employs a 9 nanosecond coaxial pulse-forming network in conjunction with a high speed Directed Energy Inc. driver to realize the voltage and current necessary to generate the fiducial spots on the film. Another problem faced by the designers was the spectral response of the Kodak TMAX400 high speed film which the experimenters use. The sensitivity of the film drops off logarithmically as the wavelength is increased from 600 nanometers to 700 nanometers. It was this loss of two orders of magnitude that drove the designers to develop new LEDs for this application. A pair of high energy, 660 nanometer LEDs were installed in the slit plate, one in either end. Referring back to the schematic in Figure 3, the drive network provides the required electronic drive for the LEDs (50v @ 5 amperes) to produce the 20 nanosecond pulse widths. It also protects the LEDs from possible excessive current due to high repetition rates which could be produced with computer control.

Although accurate, the fiducial time marks made upon the film with this system are somewhat lacking in precision. Users of the firing chamber suggested that a sharper fiducial image would certainly enhance the value of the data. When a new experiment was proposed, the opportunity for development of an improved fiducial system presented itself.

Figure 3. Firing Chamber Fiducial Generation Circuit

3. REQUIREMENTS

In support of an upcoming experiment, improved fiducial generation methods were considered. For the proposed experiment, the camera has been located approximately 300 feet away from the experiment and will receive optical data through fiber optic cables. The fibers have been terminated at the camera slit plate using special hypodermic needles to ensure proper positioning. The source of the timing initiation signal (fiducial trigger) is also approximately 300 feet from the camera. It is a capacitive discharge of approximately 1200 volts and 40 amperes with a 10% to 90% rise time of about 100 nanoseconds. It is this electrical signal which must be converted to a jitter-free optical signal. While the optical signal is required to emulate the old firing chamber fiducial parameter of a 20 nanosecond pulse width, it is only required to fire once per experiment. Of course, there are often hundreds of "dry runs" during which the system must function, but the repetition rate of the converter is on the order of one per hour.

One of the operational requirements which is a concern is temperature. Although the application is subterranean, a grout plug is to be placed within five meters of our system. This grout plug will seal a passageway which is three meters in diameter and twenty meters long. Further, the temperature within the grout can reach 160 degrees Fahrenheit (70 degrees Celsius) during several days of curing. Several mitigating factors exist to ensure that the junction temperature of the laser diode is well below this level. The area will be ventilated until shot time, ensuring a reasonable ambient temperature. The alluvium tuft walls have relatively low thermal conductivity and will serve to insulate our hardware from the grout temperature.

4. DESIGN

Our first pass involved implementing the firing chamber pulse generation hardware in a one-shot mode. A proven entity, this was expected to provide the necessary electronic drive and would leave only the LED-to-fiber coupling to be engineered. This latter detail was considered relatively trivial. Considerable testing was conducted using several high-output LEDs at wavelengths of 590, 620 and 660 nanometers. The LEDs were coupled into a one meter length of 100/140 fiber (100 micrometer core) using a Graded Index or GRIN lens. This coupling scheme was used to quantify, to a first order, the output power of the LEDs and to compare these powers to those of the slit-mounted LEDs from the firing chamber. A pulse generator was built to emulate the firing chamber driver and this test set-up was used to analyze the LEDs. Using a Tektronix model 6701 Optical-to-Electronic Converter, and taking into account the converter's reduced sensitivity to wavelengths below 850 nanometers, comparison data was taken. The optical output powers of the LEDs were all approximately 25 microwatts.

Subsequently, several of the new LEDs were coupled to a GRIN lens/fiber configuration with only marginal success. It became apparent that this type of fabrication would require greater engineering detail than our small production quantity, (and funding) would support, particularly in light of other market options such as laser diodes. Laser diodes, rated at 635 nanometers, 3.5 milliwatts continuous, were procured in a pigtailed assembly from Oz Optics. Testing was conducted to determine the actual upper limit for the continuous, as well as pulsed output power. Using an ILX 3811 Precision Pulsed Current source to generate a 100 nanosecond output pulse, tens of milliwatts of optical power were generated consistently. This disparity between LED and Laser Diode output levels eliminated LEDs from further consideration. Further, the cost for a laser diode, pigtailed into a 100/140 fiber with the appropriate connector is under \$400, making this much more cost effective.

It was at this time in the design process that a "small caveat" was introduced into our requirements. The required location for the converter was determined to be "too close to the experiment" to allow any electrical energy to be present at that location until one minute prior to shot time. This meant that the converter would have to be passive in nature. We began to focus attention on passive systems which could employ the electrical waveform at the input of the converter, not as a trigger, but also as an energy source. Although the input waveform seems to have a relatively slow rise time (100 nanoseconds), the peak current of 40 amperes is considerably more than the laser diode requirements. Thus, we began with a capacitively-coupled design where the rise time of the laser diode current tracked that of the input waveform. This configuration took advantage of the step nature of the diode lasing function and produced a sharp rise time (10-15 nanoseconds). However, the several microsecond discharge time of the input waveform increased the laser diode pulse width. Attempts were made to facilitate a rapid laser diode cutoff by using a high-speed silicon-controlled rectifier (SCR) to shunt the laser diode current. This met with modest success although pulse widths below 100 nanoseconds were difficult to achieve consistently. In an effort to generate a short pulse with a passive system, a transformer was implemented.

By using the rapid rise of the current input, (400 amperes/microsecond), a ferrite core transformer was developed which saturates at approximately 7-10 amperes. Further optimization of the turns ratio led to a viable transformer which produces a 20-25 nanosecond optical pulse width consistently. The Revision A Converter is shown schematically in Figure 4 while Figures 5 and 6 show the circuit layout. The laser pigtail assembly is mounted in the lid of the Pomona box. As shown in Figure 7, a comparison of the laser diode and LED effects upon the film reveals the improved resolution provided by the laser diode.

Figure 4. "Revision A" Electrical-to-Optical Converter

Figure 5. "Revision A" Electrical-to-Optical Converter

Figure 6. "Revision A" Electrical-to-Optical Converter

Figure 7. Comparison of Fiducial Marks - LED (top), Laser Diode (bottom)

5. APPLICATIONS

Several other applications have benefitted from this development work. One experimenter has requested that we generate a longer pulse with the same rise time. This was a result of the rather prevalent static electricity in Nevada. If care is not exercised while removing the film from the camera, static charge builds up and discharges to the film. This static discharge process produces many tiny spots on the film, not unlike the fiducial mark, creating considerable confusion for the experimenter. Thus, a "Revision B" has been developed to provide a distinctive pulse width. This revision, shown in Figure 8 is also passive and incorporates a Field-Effect Transistor (FET) switch to shunt the laser diode current after approximately one microsecond. The Revision B circuit has been successfully field tested at the Nevada Test Site and will be utilized on the next underground test.

Figure 8. Electrical-to-Optical Converter - Revision B

Another application is the upgrade for the Firing Chamber's LED fiducial system. After comparing the marks produced by the two systems, Firing Chamber experimenters were impressed with the improved resolution of the laser diode system and queried as to how this system could be implemented at the Firing Chamber. Perhaps a "Revision A" converter could be driven directly from the computer output and the camera slit plate could be modified to hold the fiber conduit. As time and funding permit, this modification is planned for the coming months.

6. CONCLUSIONS

A passive, compact, cost-effective electrical-to-optical pulse converter has been developed and fielded. It has been demonstrated that a fiber-coupled diode laser can be used for the production of high resolution fiducial markers for rotating mirror streak camera diagnostics. Modifications have also been fielded to address further customer requirements. Preliminary testing has been conducted to approximate the optical threshold level for the film and the temperature dependence of the laser diodes. Further analysis shall quantify these issues in detail.

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