# Temporal Switching Jitter in Photoconductive Switches

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## ABSTRACT

This paper reports on a recent comparison made between the Air Force Research Laboratory (AFRL) gallium arsenide, optically-triggered switch test configuration and the Sandia National Laboratories (SNL) gallium arsenide, optically-triggered switch test configuration. The purpose of these measurements was to compare the temporal switch jitter times. It is found that the optical trigger laser characteristics are dominant in determining the PCSS jitter.

Keywords: Photoconductive semiconductor switch, gallium arsenide, ultra-wideband source

## 1. INTRODUCTION

Gallium arsenide (GaAs) photoconductive semiconductor switches (PCSS) have been used for some time in high power ultra-wideband source applications.[1,2,3] In order to achieve high power, many switches are closed at the same time. For the powers of interest and under "rep-rated" conditions, this is only possible if the jitter among individual switches can be kept below approximately 40 ps. This figure is determined from the rule-of-thumb empirically determined jitter of about 10% of the rise time achieved by the PCSS. The rise time of the Air Force Research Laboratory's (AFRL) switches is approximately 350 ps. Our two research groups have pursued slightly different paths to achieve each organization's specific needs. At AFRL, high peak power results are tantamount; therefore, keeping the jitter to a minimum is essential. On the other hand, SNL also has switching needs that have focused on reliability with slower switching times. Consequently, the number of switching events before failure (lifetime studies and measurement of the mean time before failure) also has been an important yardstick for SNL[4].

Our switches are made differently and are tested under different conditions. Therefore, it was not surprising that the performance of these switches were substantially different when simply comparing achieved values reported from each laboratory. However, a careful comparison had never been attempted. Recently, we decided to select one parameter, in this case switch jitter, to study what differences and similarities exist between our two switches and the operating conditions. In order to do this, an AFRL switch was first tested for jitter in its own laboratory and then an SNL switch was checked in the AFRL laboratory. Next, jitter measurements were made on the same two switches at the SNL laboratory.

In the next section, the experimental configuration for both sets of measurements is given. Then, Section 3 reports the results obtained from each set of measurements. We then list our conclusions in the last section.

## 2. EXPERIMENTAL PROCEDURES

### 2.1 Switches under test

The AFRL switch is made from a 0.5 mm-thick GaAs wafer and has 0.25 cm opposed contact gap spacing. They are formed on a 5.08 cm diameter semi-insulating, LEC GaAs wafer from Bertram Laboratories. The Army Research Laboratory (ARL)

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processed this bulk material for AFRL in the following manner.[1] The wafer was polished and passivated with a 1000 Å layer of silicon nitride. The wafer was then coated with photoresist, and a Rogowski profile contact pattern was photolithographically defined and developed. The wafer was then placed in a reactive ion etcher, and the silicon nitride layer was removed in the patterned area. The contacts are formed by placing the wafer in an E-beam evaporator and depositing 50 Å Ni, 750 Å Ge, 750 Å Au, 750 Å Pd, and a 2000 Å Au cap onto the wafer. The wafer was then soaked in warm acetone to facilitate metal lift-off. The entire process was then repeated for the opposite side of the wafer, and a final rapid thermal anneal was performed at 480° C for 10 seconds. The result obtained after dicing the wafer into individual components is a set of n-i-n semiconductor switches made from through the bulk of GaAs that we use in our laboratory experiments.

Switches made at SNL are processed from both LEC and VGF GaAs wafers, using both 2 and 3 inch diameter wafers. P and N ohmic contacts are made from Au-Be and Ni-Ge-Au-Ni-Au metallizations respectively. Such contacts have much greater longevity operating under forward bias conditions. As shown in Figure 4, both contacts are made to the top surface of the wafer, in contrast to the opposed contact geometry employed in the AFRL switches. Like the AFRL switches, the contacts are patterned using photolithographic lift-off and a ~1000 Å layer of silicon nitride is used to passivate the GaAs surface in the switch gap. 2.5 mm gap switches were used as a direct comparison to the AFRL switches.

## 2.2 Testing configurations

### 2.2.1 AFRL test configuration

We performed experiments in the AFRL 1590 bay laser laboratory to determine the difference in temporal switching jitter characteristics between the two switch types when implemented in the AFRL test fixture.

The temporal switching jitter is measured as the rms jitter in the time delay between the electrical signal that triggers the laser diode and the electrical signal generated by the closure of the PCSS. In the test fixture (see Figure 1), the coarse experiment timing is generated using the two positive going pulse outputs of a Stanford Research Systems DG-535 pulse generator. The first output (AB) was used to trigger the high-voltage modulator that charges the PCSS pulse forming line. The second output (CD) is delayed by 800 ns and used to trigger a Picosecond Pulse Labs model (PSPL) 4000E pulse generator. The 800 ns delay allows sufficient time for the PCSS pulse forming line (PFL) to be charged and for stray capacitances to be discharged prior to PCSS closure. The PSPL pulse generator is used to generate a fast-rising (~ 100 ps) trigger event for both the PCSS laser diode trigger and the SCD-5000 oscilloscope. For the results reported here, the diode trigger consisted of a 904 nm wavelength Laser Diodes Incorporated (LDI) solid state laser with 15 – 20 μJ/pulse. When triggered in this manner, the measured temporal switching jitter includes the laser diode jitter, the SCD-5000 jitter and the PCSS jitter. The temporal trigger jitter of the SCD-5000 has been measured by splitting the PSPL output; using one half to trigger the oscilloscope and using the other half as the input signal. In this manner, the SCD-5000 trigger jitter was measured as approximately 6 ps rms and the laser trigger jitter was not measurable.

During the temporal switching jitter tests, the PCSS was fired at approximately 1 Hz for 10 shots. Each shot was stored in one of the 16 memory locations of the Tektronix SCD-5000 oscilloscope. At the end of the 10 shot sample, the time delay of each switching event was measured manually from the oscilloscope and entered into a spreadsheet. This time delay is the time (as measured from scope zero) for the pulse to reach half its maximum voltage. This process was repeated several times to determine an overall temporal jitter average. Finally the spreadsheet was used to calculate the rms standard deviation of the time delay values.

### 2.2.2 SNL test configuration

Testing at SNL was performed using a very similar apparatus and method for determining the timing jitter between the triggering signal and the PCSS closure. The key differences in the SNL experiment were the use a slower HV modulator to pulse-charge the circuit (~10 μs vs. 300 ns rise time) and the use of an 880 nm fiber coupled diode laser (EG&G Canada Optoelectronics) for triggering the PCSS. This diode laser supplies pulses of ~ 1μJ energy with a rise time of approximately 5ns. The aforementioned trigger laser used by AFRL was also tested at SNL to afford a direct comparison of system performance using the two lasers.

## 3. EXPERIMENTAL RESULTS

The data from the AFRL tests are shown in Table 1 where the spreadsheet calculations are reproduced. All switching times in the table are measured in nanoseconds. The same AFRL/ARL switch was used for each of the four sets of data (PCSS1, PCSS2, PCSS3 and PCSS4). Likewise, the same SNL switch was used for the three sets, SAND1 – SAND3. As can be seen from the table, the average standard deviation measured for the AFRL/ARL switch was 34.2 ps. The SNL switch had a similar temporal jitter of 41.6 ps. Figure 2 shows one of the sets of data from the AFRL/ARL switch. One of the SNL switch data sets is depicted in Figure 3. The reason that the pulse widths varied on one shot with the AFRL switch and each shot for the SNL switch as the tests progressed has not been exactly determined, but early breakdown of some part of the load circuit is a likely cause. Thus, both types of switches, when operated in the AFRL test fixture, exhibit similar temporal jitter characteristics.

The same devices were tested at SNL to reveal the differences in system jitter performance due to the use of slower pulse charging and a slower fiber-coupled trigger laser with less optical energy. The data show conclusively that the trigger laser characteristics are critical in obtaining low (<50 ps) jitter performance. Figure 5 shows the effect on timing jitter between using the fiber coupled laser and the lens imaged laser, both sets of data taken using 17-18 kV charge voltage on an AFRL switch. More than a threefold reduction (97 vs. 29 ps) of timing jitter is observed using the faster, more powerful laser trigger. The fact that this low jitter was obtained with the slower pulse charger and similar performance (~ 41 ps) was also obtained using a coplanar SNL switch shows that the trigger laser characteristics are the dominant factor in timing jitter performance.

The fast (~ 200 ps) rise time of the trigger laser used by AFRL is a key factor in obtaining low PCSS timing jitter. However, it is also critically important to obtain sufficient optical pulse energy and optimal alignment of the laser image in the switch gap. As shown in Figure 6, the data indicates that it is necessary to deliver greater than about 3 μJ of optical pulse trigger energy to obtain consistently low jitter. We also characterized the sensitivity of timing jitter performance to laser alignment. As shown in Figure 7, this sensitivity is very significant, with a displacement of only ~ 0.1 mm (a small fraction of the 2.5 mm gap) causing over a doubling of the timing jitter. It is likely that optimizing these factors results in low timing jitter when the PCSS triggers on the fast leading edge of the laser temporal profile. Once the PCSS triggers, the remainder of the optical pulse energy is of negligible effect. Thus it may be possible to obtain low jitter using a lower energy fiber-coupled laser if sufficient energy can be delivered within ~ 200 ps or less, e.g. a gain-switched pulsed laser.

## 4. CONCLUSIONS

Despite the fact that the AFRL/ARL switch and the SNL switch are significantly different in construction and were manufactured using different processes, the temporal switch jitter results are strikingly similar when tested under identical conditions. The additional comparison made when the AFRL laser was used in the SNL test configuration confirms the fact that the temporal jitter for such solid state photoconductive switches is primarily a function of the laser trigger turn-on characteristics.

AFRL has recently started to receive switches from the Naval Surface Warfare Center (NSWC) at Dahlgren, VA. [5] Future plans will include comparison of the jitter of these switches with the others discussed here.

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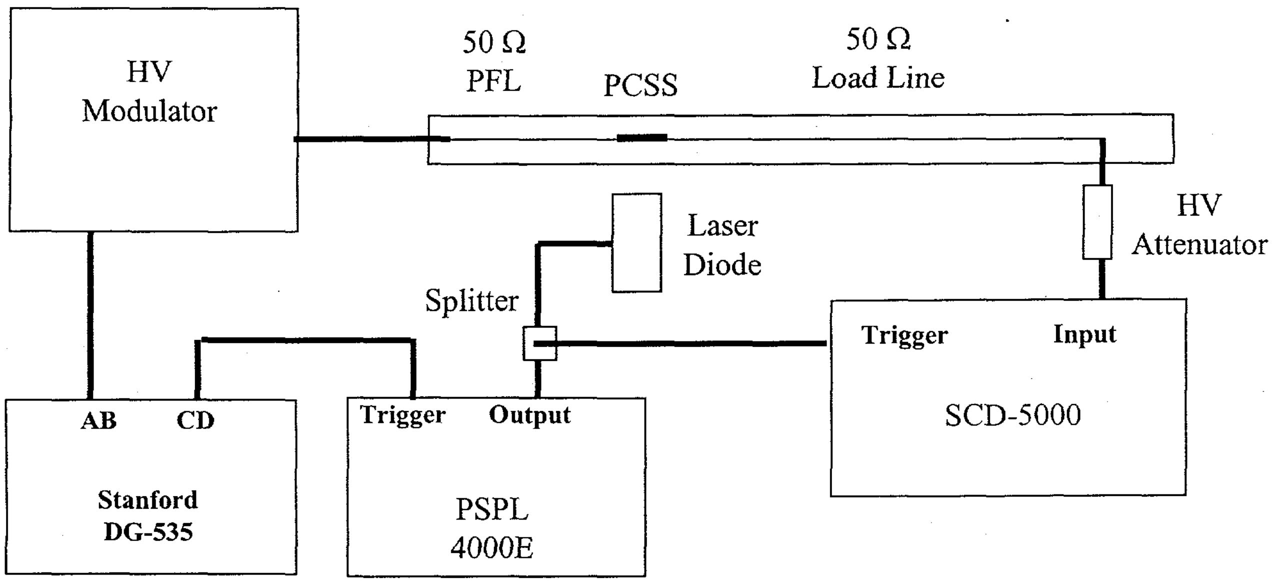


**Figure 1. AFRL laboratory setup for switch comparison measurements**

| Switch tests on Feb 22, 00 | | | | | | | |
|---|---|---|---|---|---|---|---|
| ARL (PCSS) and Sandia (SAND) Switches | | | | | | | |
| **Title** | **PCSS 1** | **PCSS 2** | **PCSS 3** | **PCSS 4** | **SAND 1** | **SAND 2** | **SAND 3** |
| Shot 1 | 1.8523 | 1.124145 | 1.036168 | 1.593353 | 1.84262 | 0.537643 | 2.717498 |
| Shot 2 | 1.886608 | 1.192571 | 1.187683 | 1.583578 | 1.823069 | 0.483871 | 2.737048 |
| Shot 3 | 1.871945 | 1.207234 | 1.163245 | 1.593353 | 1.915934 | 0.532747 | 2.707722 |
| Shot 4 | 1.84262 | 1.129032 | 1.148583 | 1.603128 | 1.803519 | 0.542522 | 2.761486 |
| Shot 5 | 1.847507 | 1.177908 | 1.15347 | 1.617791 | 1.764418 | 0.56696 | 2.785924 |
| Shot 6 | 1.886608 | 1.177908 | 1.177908 | 1.554252 | 1.793744 | 0.542522 | 2.795699 |
| Shot 7 | 1.906158 | 1.246344 | 1.138807 | 1.588465 | 1.764418 | 0.522972 | 2.771261 |
| Shot 8 | 1.871945 | 1.236559 | 1.143695 | 1.549365 | 1.783969 | 0.513196 | 2.825024 |
| Shot 9 | 1.906158 | 1.197458 | 1.231672 | 1.578915 | 1.871945 | 0.518084 | 2.820137 |
| Shot 10 | 1.896383 | 1.197458 | 1.212121 | 1.593353 | 1.901271 | 0.54741 | 2.849462 |
| | | | | | | | |
| **Standard Dev.** | 0.0235075 | 0.0395611 | 0.0528824 | 0.0207537 | 0.0548172 | 0.0227158 | 0.0472072 |
| **Average** | 1.8768232 | 1.1886617 | 1.1593352 | 1.5855553 | 1.8264907 | 0.5307927 | 2.7771261 |
| | | | | | | | |
| **PCSS Avg. Standard Dev.** | 0.0341762 | | | | | | |
| **SAND Avg. Standard Dev.** | 0.0415801 | | | | | | |
| | | | | | | | |
| Vpp | 18 kV | 18 kV | 18 kV | 18 kV | 12 kV | 16 kV | 18 kV * |
| Vlaser | 325 V | 325 V | 325 V | 300 V | 400 V | 400 V | 400 V |
| Tpp-I | 1.0 us | 1.0 us | 1.0 us | 1.4 us | 2.4 us | 2.4 us | 1.0 us |
| Switch | PCSS | PCSS | PCSS | PCSS | SAND | SAND | SAND |
| | | | | | | | |
| Shortened Pulse Width | | | | | | | X |
| Adjusted Laser Alignment | | | | X | | | |

**Table 1. Switch comparison results as measured at AFRL's laboratory. Switching times are in nanoseconds.**

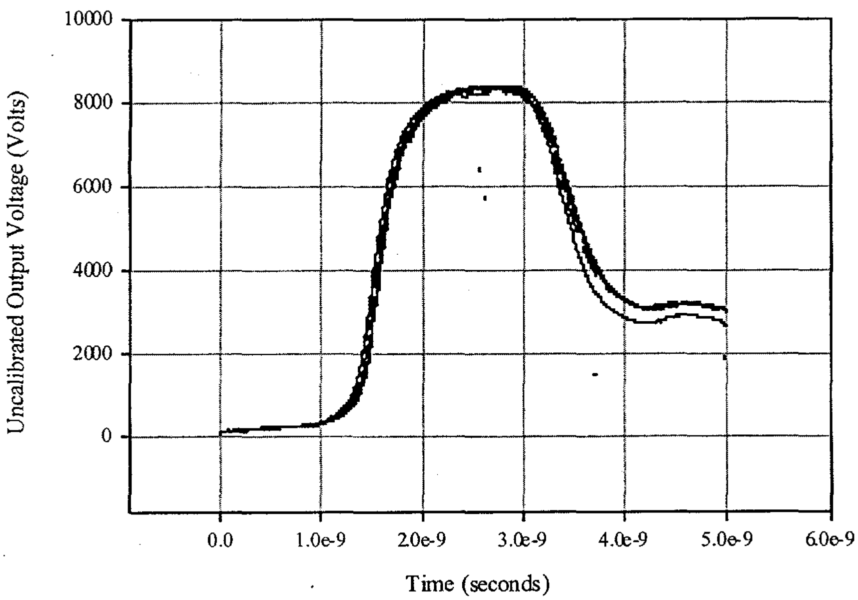


**Figure 2. Overlay plots of AFRL (ARL) switch results (PCSS 4) in AFRL laboratory testing configuration.**

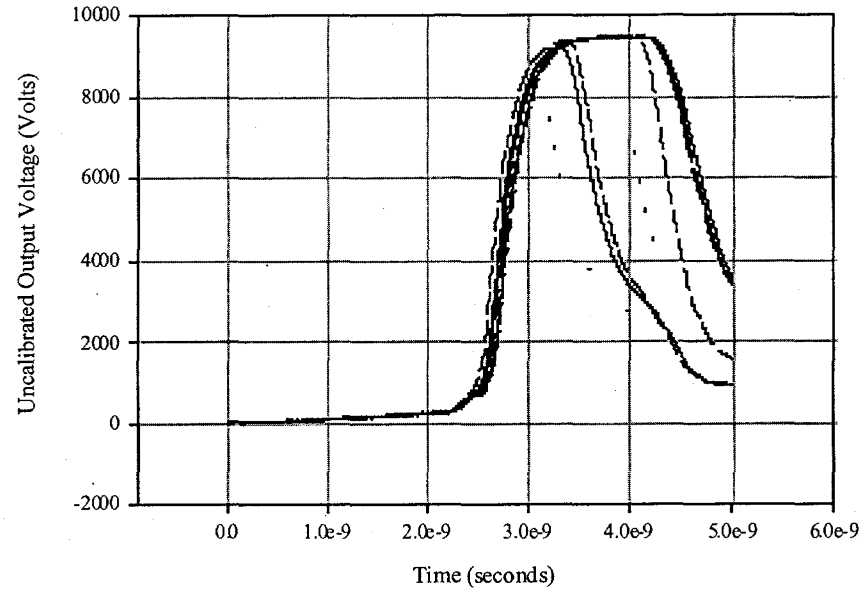


**Figure 3. Overlay plots of SNL switch results (SAND3) in AFRL laboratory testing configuration.**

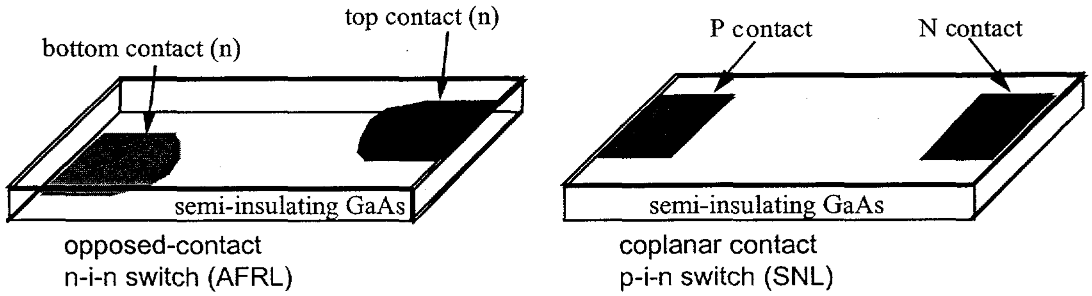


**Figure 4. A comparison of opposed contact (AFRL) and coplanar (SNL) switch geometries used in the experiments.**

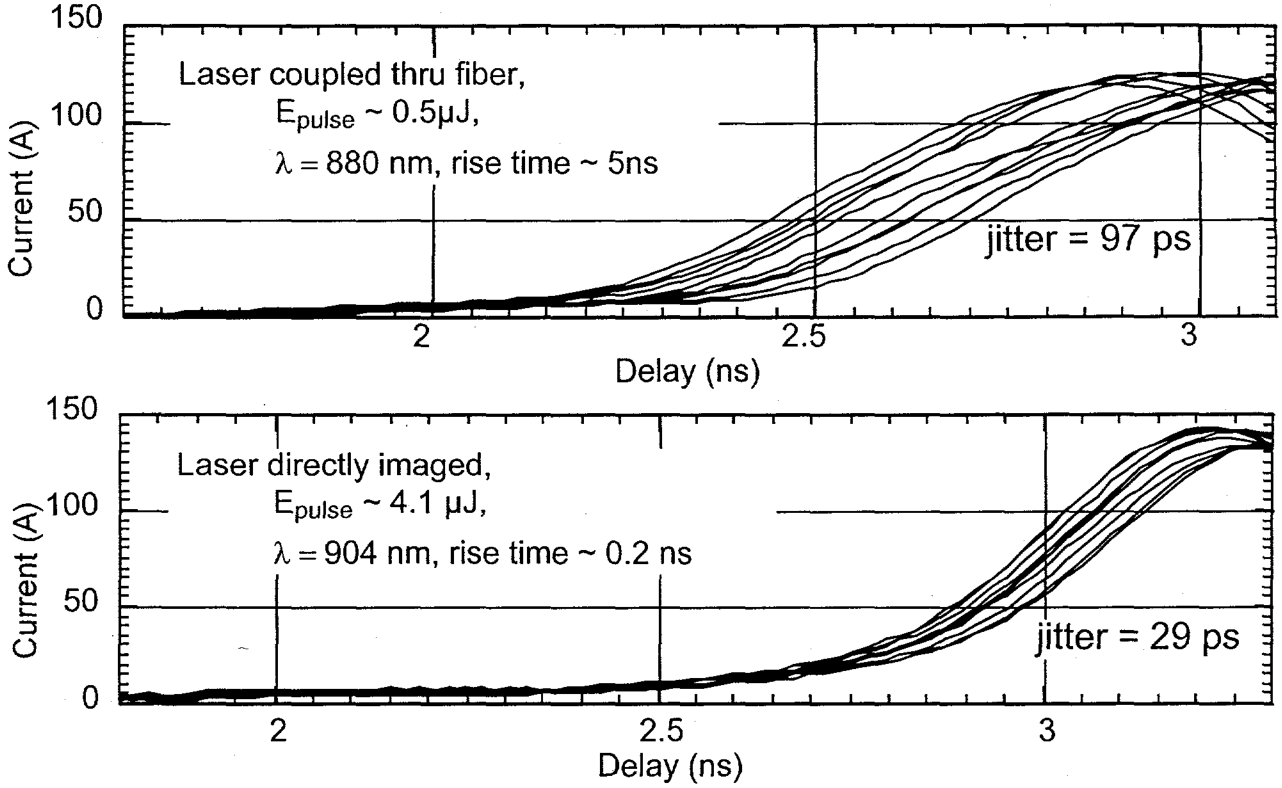


**Figure 5. Overlaid PCSS current waveforms showing decreased timing jitter with use of AFRL laser trigger.**

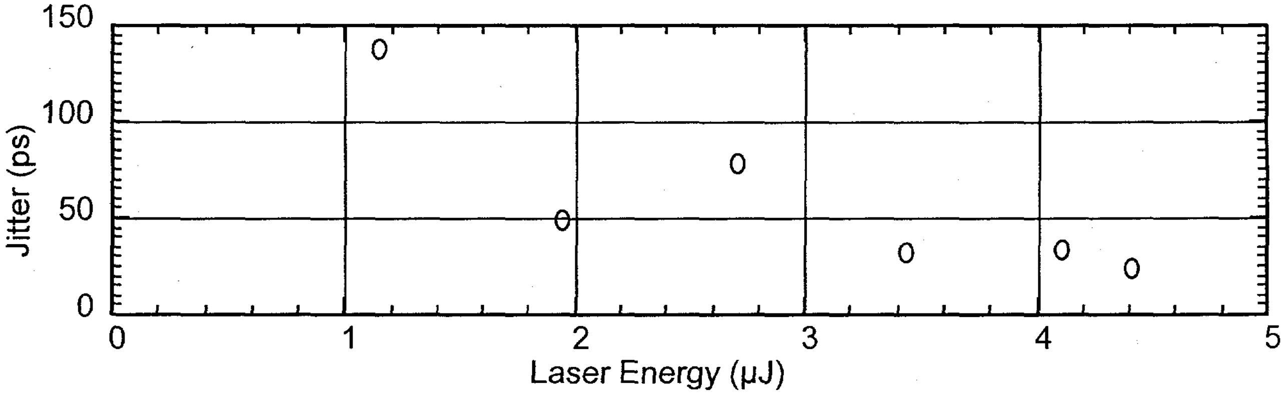


**Figure 7. Variation of timing jitter vs. trigger laser optical energy.**

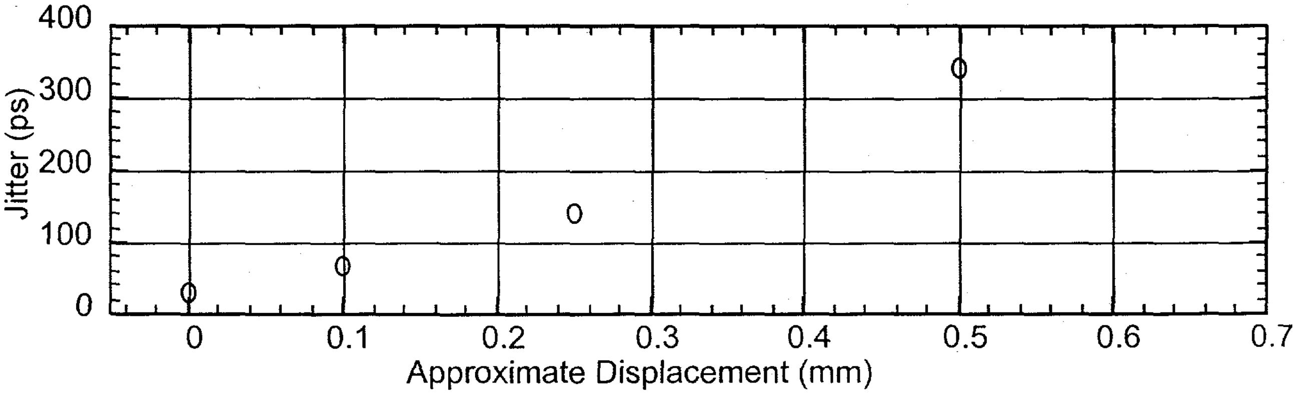


**Figure 8. Variation of timing jitter vs. trigger laser displacement from alignment for jitter minimum.**

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