

# THE EXPLOSIVE PULSED POWER TEST FACILITY AT AFRL

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## *Abstract*

The Air Force Research Laboratory has developed and tested a variety of explosive driven pulsed power devices over the past twenty-two years. Testing is performed primarily at a dedicated facility located at Chestnut Site on Kirtland Air Force Base. The facility is described in this paper, including details of recent upgrades.

## I. BACKGROUND

Chestnut Site is an explosive testing range located on Kirtland Air Force Base, Albuquerque, NM. It is used by a several government agencies for studying explosive devices and effects. The site is rated for explosive test up to 450 kg of high explosive (HE).

Twenty-two years ago, the Air Force Research Laboratory established a facility for testing explosive-driven pulsed power devices at Chestnut Site. This facility consisted of a single firing site for testing flux compression generators (FCG), a remotely-located control trailer and supporting diagnostics. A variety of FCG devices have undergone development testing [1,2,3] at this facility. Over the last four years there have been several upgrades to the explosive pulsed power test facility, the principal one being the addition of a second firing site for testing explosive-driven switching devices.

The original firing site included a capacitor bank to provide seed current, a small bunker for X-units to fire detonators and a protected enclosure for a Beckman Whitley framing camera. Upgrades to this firing site include a shielded area for fiber-optic devices near the firing pad and a buried vault for cable connections to the shielded data collection system. Details of Firing

Site #1 are given in Section II and the shielded data collection system is discussed in Section IV.

Firing Site #2 was established in 2003 to provide the capability for testing high current opening switches. A large, trailer-mounted capacitor bank can provide currents up to 3 MA to devices under test. When the quantity of explosive is small (<3 kg), testing is performed inside an 8 ft diameter reinforced concrete pipe, closed at one end. The pipe shields the capacitor bank from shrapnel and also reduces the over-pressure on the trailers. An area for fiber optics and a connection to the shielded data collection system are also provided. Details of Firing Site #2 are provided in Section III.

This paper concludes with a brief discussion in Section V of the changes to our timing and firing system brought about by the availability of fiber optic control and communications.

## II. FIRING SITE 1

The layout of Firing Site #1 is shown in Fig. 1. The firing pad, GZ, is on bare earth and its exact location is constrained only by the framing camera line-of-sight and connections to power and diagnostics.

Seed current is provided by a small capacitor bank, SB, housed in a transportable enclosure that is protected by a concrete block wall and a blast deflector. The enclosure is isolated from ground shock by a layer of used automobile tires. The bank has a capacitance of 515  $\mu\text{F}$  and a maximum charge voltage of 15 kV. In routine use the bank provides a seed current of 5 to 10 kA to a 300  $\mu\text{H}$  FCG. The maximum discharge current is 100 kA, the operating limit of the switching ignitron. The bank is operated by a custom-built controller linked fiber-optically to the remote control trailer. Bank current and its derivative are measured by a

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Pearson transformer and a Rogowski coil, respectively. The waveforms are recorded locally and read out post-shot on a fiber-optically coupled GPIB link.

Current from the bank is carried to the vicinity of the firing pad by 6 parallel YX-198 cables. The cables are routed underground through a 152 mm (6 in) diameter PVC pipe. Careful attention is paid to the cable supports so that there is good voltage isolation between the cables and earth ground. The capacitor bank cables terminate in a Hoffman enclosure about 6 m (20 ft) from GZ. Final connection to the FCG is made with one or more disposable coaxial cables.

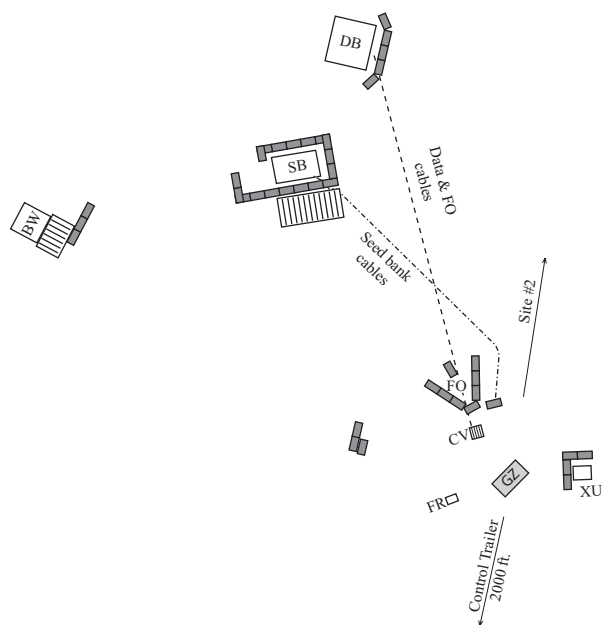


Figure 1. Layout of Firing Site #1.

Recently, the bank hardware and controller were modified to eliminate all connections to earth ground during discharge (except the output cables). This permits the input terminals of an FCG to float as much as 5 kV above ground during operation without generating ground loop current.

Electrically triggered X-units are housed in a steel cylinder, XU, protected by a concrete block wall. These X-units are part of the original firing site installation and have been in use for many years. However, their electrical cable connections pose an additional risk for breakdown to earth ground if the FCG input is driven to high voltage during operation.

Over the past five years, we have been moving to eliminate these X-units in favor of fiber-optically controlled X-units. These X-units and their power sources are located behind a V-shape concrete block wall, FO. Twenty-four optical fibers run underground from FO to the diagnostic bunker, DB. These fibers are used for X-unit control and also for carrying fiber-optically coupled data signal to the diagnostic recorders when needed.

Electrical diagnostics of FCG performance are carried out using only non-contacting sensors, usually Rogowski coils or Pearson transformers. These signals are carried on disposable coaxial cables to a buried concrete vault, CV, containing a patch panel in a Hoffman box. Cables from the patch panel run underground to the diagnostic bunker, DB. Details of this diagnostic installation are discussed in Section IV.

A visual record of FCG behavior can be obtained with a Beckman Whitley Model 189A framing camera. The camera is mounted in a transportable enclosure, BW, protected by a blast deflector. The camera records 25 frames on 35 mm film. For FCG testing, the camera is typically operated with an inter-frame time of 5 to 7  $\mu$ s to encompass the full operating time of 125  $\mu$ s. When recording images with the framing camera, the FCG is illuminated with one or two shocked-argon light sources driven by Detasheet explosive.

### III. FIRING SITE 2

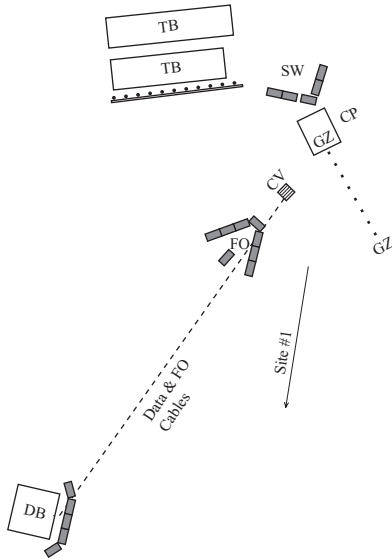
Firing Site #2 is a recent addition to the facility. Its principal purpose is the testing of explosive-driven opening switches. Explosive-driven opening switches typically operate at multi-megampere current and are used in conjunction with an FCG to generate high voltage or a fast-rising current. It is much more cost effective, however, to use a capacitor bank current source rather than an FCG for developmental testing.

The capacitor bank at Firing Site 2 was originally a trailer-mounted, high voltage Marx bank<sup>1</sup> for EMP testing. It was reconfigured for us by Titan Pulse Sciences into a single-stage, high-current bank. The bank consists of eight 0.51 mF modules mounted in two trailers the size of conventional tractor-trailer rigs. These trailers, however, have fiberglass rather than metal shells because of the original high voltage application. The trailers also contain power supplies and charging controls but no switching components.

The location of the trailer banks is marked TB on the site layout, Fig. 2. Since the trailers are only 70 m from Test Site #1, a protection wall was erected to shield them from the direct pressure wave. The wall is sufficient protection for tests using up to 35 kg of HE at Site #1. When more than 35 kg of HE are used at Site #1, the trailers are removed from Site #2 and parked at a remote location.

Switching is accomplished externally at SW using RP-1 detonators. Each pair of bank modules is switched by three RP-1 detonators that drive a copper jet through 1.5 mm (0.06") of sheet Mylar insulation. Because the detonators are raised to high voltage after the switches close, fiber-optically isolated X-units are required for these switches. For loads that do not provide a crowbar function, a separate explosive-driven

crowbar switch is added. This switch crowbars all eight bank modules in parallel using six RP-1 detonators.



**Figure 2.** Layout of Firing Site #2.

A maximum operating voltage of 35 kV has been set (~87% of rated voltage) to extend capacitor lifetime. The peak bank current is about 3 MA into a low inductance load (<150 nH) and testing is performed routinely at 2+ MA.

The location of the firing pad for Test Site #2 is somewhat more flexible than Site #1 because there is no requirement to stay in the field of view of a framing camera. Low energy experiments that do not require a crowbar switch are performed in a 2.4 m (8 ft) diameter, steel-reinforced concrete pipe located at CP in Fig.2. The end of the pipe facing the trailer bank is closed except for a small hole for the seed current cables. This location minimizes cable inductance and, thus, the required charge voltage for a given current. If a crowbar switch is required, then the firing pad moves outside the concrete pipe to provide room for the crowbar assembly. By moving further away, larger explosive charges can be accommodated, up to a limit of about 10 kg.

A V-shaped shield area for fiber-optics and a buried cable vault, identical to the installation at Test Site #1, are located close to the concrete pipe. Underground connections to these terminals lead to the common diagnostic bunker, DB.

#### IV. DIAGNOSTICS

The new data collection and recording system was designed and installed in 2003. The principal design goal for the new system was to improve the quality of

recorded data by reducing noise pickup and eliminating ground loop currents. The three major changes in the new system are; installation of a concrete bunker near the firing sites to reduce the length of cable runs, electrical shielding around data cables to minimize noise pickup and implementation of a rigorous single-point grounding scheme.

The concrete bunker for data recording was obtained as surplus from another project. It is a single room, 3 m (10 ft) by 3.3 m (11 ft) interior area with a 2.3 m (7' 8") ceiling height. The walls, floor and ceiling are 0.2 m (8 in) thick, steel reinforced concrete. A single steel door provides access. The bunker was placed equidistant from the two firing sites at a distance of about 36 m (120 ft).

Within the bunker there are three equipment racks that house oscilloscopes, timing generators, and fiber-optic transmitters and receivers. The equipment racks are insulated from ground except for connection to the electrical shield system. The equipment racks contain three UPS units to provide power during an experiment. Operation is typically switched from line power to UPS power about 5 minutes before an event.

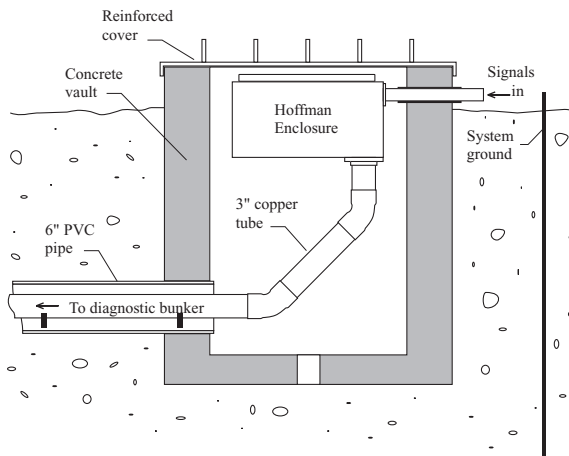
Data is recorded on a bank of Tektronix four-channel oscilloscopes. These scopes all have GPIB capability for control and data transfer. The GPIB electrical signals are converted to serial fiber-optic signals for transmission to the remote control trailer. Setup of the oscilloscopes and read-out of the recorded data is carried out from the remote control trailer. With the exception of the shielded data cables, all of the other signals entering and leaving the equipment racks, e.g., timing and control, are transmitted over optical fibers.

Figure 3 shows the principal features of the electrically shielded data collection system. Coaxial cables are run from a buried concrete vault, CV, near each firing pad to the diagnostic bunker through 76 mm (3 in) rigid copper tube. The copper tube acts as a Faraday cage around the cables to eliminate capacitive coupling to the outer braid of the cables. Each 3" tube contains 18 cables, 14 type RG-8 and four Foamflex cables for high frequency signals.

The copper tube runs underground to protect it from shrapnel. To prevent the copper tube from contacting earth ground, the tube runs inside a 152 mm (6 in) diameter PVC pipe. Support blocks keep the tube centered in the pipe, and the pipe is installed with sufficient slope so that any moisture condensing in the pipe will drain away.

The copper tube terminates at a Hoffman enclosure inside the buried cable vault. A 32 mm (1.25 in) copper tube passes through the vault near ground level to provide an entrance for signal cables. This tube can accommodate eighteen RG58 or RG223 cables. A copper grounding rod is located immediately adjacent to the buried vault. This is the one and only grounding

point permitted for both the data collection system and the experimental apparatus.



**Figure 3.** Electrically shielded diagnostic system.

Connections from the cable vault to the experiment can be made in two different ways, depending on the degree of shielding required. For routine experiments a 76 mm (3 in) wide copper or aluminum foil strip is run from the 1.25" tube leaving the vault to the experimental apparatus. The foil is insulated from ground with 0.25 mm (0.01 in) thick polyethylene or Mylar. Signal cables are laid on top of the foil strip and sand-bagged in place. For experiments that generated large external fields or that produce very low-level signals, the signal cables are carried to the experiment inside 25 mm (1 in) rigid copper tubing. Connections are made with conventional copper tube fittings that are slotted and clamped with hose clamps. The 1" tube terminates in a junction box at the experiment and individual signal cables are carried to the apparatus in 9.5 mm (3/8 in) diameter soft copper tubing. Standard brass fittings, compression to NPT, connect the tubing to the apparatus. The diagnostic sensors and the signal cables are all carefully insulated from the shield system and the apparatus to prevent ground loop current from being coupled into the oscilloscopes in the diagnostic bunker.

Another capability added in recent years is a Faraday Rotation diagnostic for measuring high currents. This diagnostic is now used regularly for experiments that produce a peak current greater than 1 to 2 MA. Faraday Rotation has two important advantages; the calibration is intrinsic to the optical fiber and the technique is immune to electrical noise generated by the experiment. Counterbalancing these advantages are several drawbacks including, sensitivity to birefringence in the fibers, false readings caused by mechanical motion of the fiber during the experiment, and the possibility of ground loop noise affecting recording of the signals. For this reason, the Faraday Rotation measurements are always performed using

two fibers (for redundancy) and they are always backed up with dual Rogowski coil measurements.

## V. CONTROL AND FIRING

Explosive testing is inherently a one-shot operation and it is both expensive and time consuming to repeat a test that produces flawed data. Over the past five years we have been working to replace the previous control and firing system with a fiber-optic system. The fiber-optic system is essentially complete and has proven very advantageous. The most important advantage is eliminating a potential source of ground loop current that has caused data loss in the past.

The fiber optic system has also allowed us to centralize the timing system in the diagnostic bunker close to the firing sites, thus eliminating about 7  $\mu$ s of transit time delay to the remote control trailer and back. Details of the fiber optic system can be found in a companion paper [4].

## VI. REFERENCES

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<sup>1</sup> On loan to AFRL from the Defense Threat Reduction Agency.