PerkinElmer, Inc. is a $1.7 billion high technology company based in Boston, Massachusetts, operating in four businesses—Life Sciences, Fluid Sciences, Optoelectronics, and Analytical Instruments. The Company has operations in over 125 countries, and is a component of the S&P Index.

PerkinElmer Optoelectronics is The Lighting, Imaging and Telecom Solutions Company based in Santa Clara, CA. PerkinElmer is a world leader in developing Optoelectronics products and services for many attractive markets. With more than 50 years of experience, Optoelectronics has the knowledge, the commitment, and the resources to provide complete solutions. By accelerating the development of new products and applications, leveraging our operations in Asia, Europe and North America, and incorporating Six Sigma into all that we do, we're building a premier customer franchise.

Lighting

Building on strong customer partnerships, Optoelectronics is driving growth by "selling up the value chain." We offer complete customer solutions incorporating our xenon, mercury, metal halide and fluorescent lighting technologies. Applications range from analytical instrumentation and fiber optic illumination to advanced video projection and photographic flash systems.

Imaging

The leader in amorphous silicon technology, Optoelectronics produces the semiconductor panels that are the critical components of digital x-ray systems. Imaging products are grouped in four offerings; Industrial Imaging, Medical Imaging, Analytical Instruments and Consumer based applications.

Telecom & Sensors

Optoelectronics is a world-class provider of components and solutions for the Telecom industry with expertise in optical semiconductors, micro optic component integration, high volume manufacturing, and high-performance fiber optic test equipment. This segment is propelled by the explosive growth of the Internet and the resulting demand for high-speed, high-bandwidth fiber optic equipment.

The PerkinElmer triggered spark gaps consist of three electrodes in a hermetically sealed, pressurized envelope.Their applications fall into two broad categories, each involving capacitor switching at low impedance levels.

1. A protective device, where the gap is used to crowbar energy storage elements such as filter capacitors and Pulse Forming Networks (PFNs), thereby providing shunt protection of RF tubes and other circuitry.

2. A series switch, where energy is discharged rapidly into a load. Such loads include flashlamps, electrically pumped gas lasers (such as excimer, nitrogen and CO2), medical lithotripters, EBWs, Marx generators, Kerr cells, and Pockels cells.

Although they are simple in both circuitry and function, triggered spark gaps must be operated correctly for optimum results. This description of triggered spark gaps, their ratings and their operating characteristics is intended to help the user to maximize the advantage of these devices in any given application.

Data sheets are available that list the characteristics of various standard gap types. These standard types are also available with modified operating ranges to accommodate particular circuit requirements.

Construction

PerkinElmer triggered spark gaps are built with a heavy-walled ceramic body cylinder brazed at each end to convex refractory metal electrodes. One electrode has an open area to accommodate the trigger probe and its insulating bushing. The trigger probe is always located in the center of the adjacent electrode and facing the opposite electrode. Therefore, the three elements in a triggered spark gap are referred to as the trigger, the adjacent electrode and the opposite electrode (See Figure 1).

To construct the gap, the parts are first brazed together at approximately 800°C. The assembly is then baked out at several hundred degrees Centigrade on a high-vacuum pump system to remove impurities. After the bake-out period the proper gas mixture is introduced at a pressure determined by the required Static (Self) Breakdown Voltage (SBV).

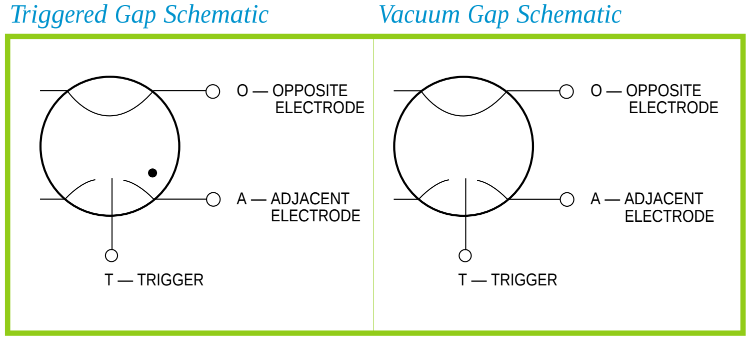
Following electrical test, the gap is cleaned, nickel plated and then given a final electrical test. The finished device is extremely rugged, both mechanically and electrically.

Ratings and Operating Characteristics

The triggered spark gap can change quickly from a near-perfect insulator to a low-impedance con-

Figure 1.

Triggered Gap Schematic *Vacuum Gap Schematic*



ductor in response to voltage applied to the electrodes. The two main electrodes carry the load current after conduction is initiated by a trigger electrode. Triggered spark gaps are generally characterized by a peak current capability of tens of thousands of amperes, delay times of tens of nanoseconds, arc resistance of tens of milliohms, inductance of 5 to 30 nanohenries and a life of thousands to millions of shots depending on the application. Typical current pulse widths are in the range of 100 nanoseconds to tens of microseconds.

As an aid to understanding spark gap ratings, each operating parameter is defined and discussed below along with other terms and concepts frequently encountered in triggered spark gap applications.

The ratings and behavior of a triggered spark gap are governed by its transfer characteristics, i.e. the voltage conditions that will cause a trigger spark to transfer to the main electrodes, or, more correctly, cause the trigger spark to initiate complete gap breakdown and conduction of current between the main electrodes. The Transfer Characteristic Curves shown in Figure 2. The Voltage-Current Waveform is shown in Figure 3.

When the minimum trigger voltage required to initiate a complete breakdown is plotted against main electrode (E-E) voltage, a curve typical of all triggered spark gaps results (Figure 2). This curve defines a region on the left where firing does not ordinarily occur called the cutoff region, a central region called the normal operating region, and a region on the right beyond the point marked static breakdown voltage, in which region the gap self-fires simply from over-voltage on the two main electrodes.

The important aspects of the transfer characteristic curve are:

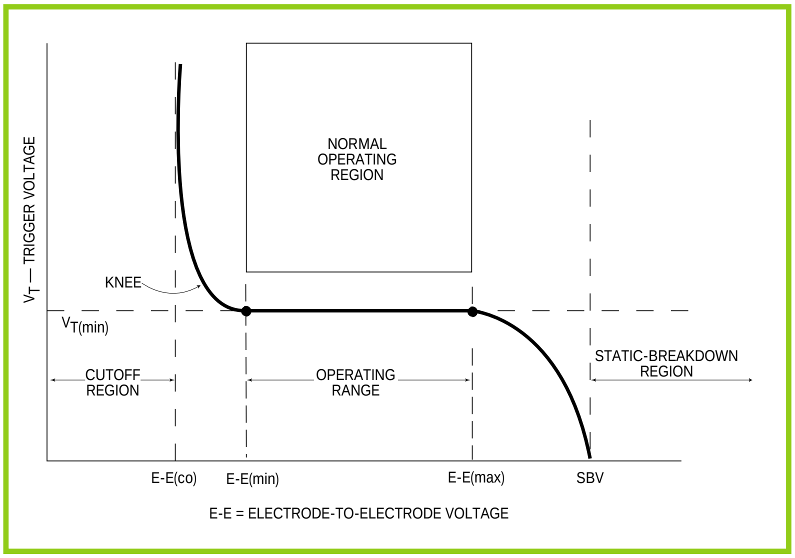
$V_{T\ (min)}$ – Minimum Trigger Voltage, the minimum open circuit trigger voltage for reliable triggering. Spark gaps should be operated well above the minimum trigger voltage.

E-E (co) - Cutoff Voltage, the main electrode voltage (E-E) marked by a sudden rise in the minimum trigger voltage as the E-E voltage is reduced. Cutoff voltage is defined as the E-E value below which trigger charge injection fails to initiate an avalanche breakdown of the gap. Operation near cutoff should always be avoided, particularly operation near the knee of the transfer characteristic curve.

E-E(min) - Minimum Operating Voltage, the minimum main electrode voltage for reliable operation. It is approximately one-third of the maximum operating voltage.

E-E(max) - Maximum Operating Voltage, typically 80% of the static or self-breakdown voltage, SBV. The value of E-E(max) is chosen to prevent random prefires.

Figure 2. Transfer Characteristics



SBV - Static (Self) Breakdown Voltage, the minimum E-E voltage such that the gap will always self-fire with no trigger voltage applied. Pressure fill and electrode spacing determine this voltage.

Range is the spread between the minimum and maximum operating voltages. Normal gap operating range typically has a 3:1 ratio (i.e. maximum-to-minimum operating voltage). For the most reliable operation with minimum delay time and jitter, triggered spark gaps should usually be operated at the high end of the range, between 60 and 80% of SBV. Operation at 50 to 70% of SBV may give longer usable life at high energy, and such operation is appropriate if delay time is not critical.

Delay Time (tad) is the time between trigger voltage breakdown and main gap conduction, as shown in Figure 3. Delay time is a function of E-E voltage, trigger waveshape, and trigger mode. Minimum delay time is achieved at the upper end of the E-E range when a fast trigger is applied and the gap is operated in the appropriate mode as described below.

Jitter (tj) is the shot-to-shot variation in delay time plus the shot-to-shot variation in trigger breakdown time. Jitter may be minimized by using a fast-rising trigger pulse at a voltage level in excess of the specified minimum.

Trigger Mode

There are actually four transfer characteristic curves for any given triggered spark gap, depending on the trigger mode, a term applied to the relative polarities of the opposite, adjacent, and trigger electrodes. These mode designations are shown schematically in Figure 4. Since the electrode polarities determine the details of the gap electric field, they significantly affect the formative stages of the discharge. Therefore, the operating range, delay time and minimum trigger voltage all depend on the trigger mode.

Figure 3. Typical Current Waveform Characteristics

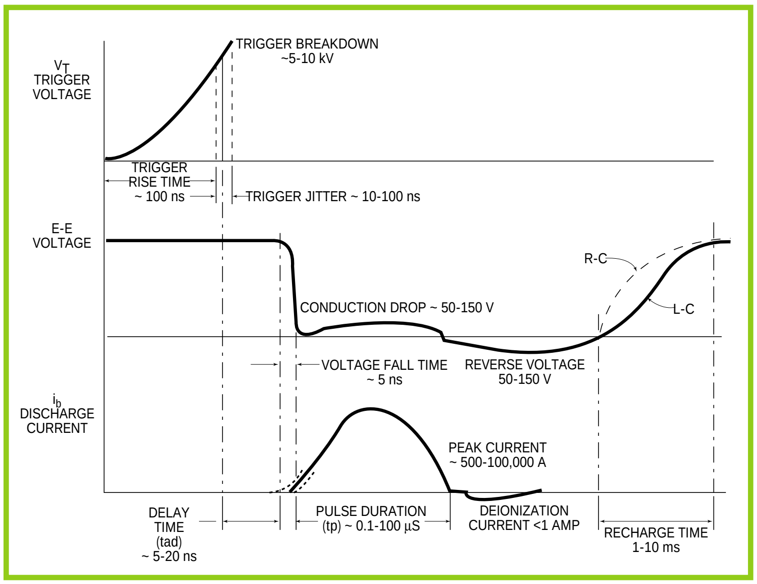
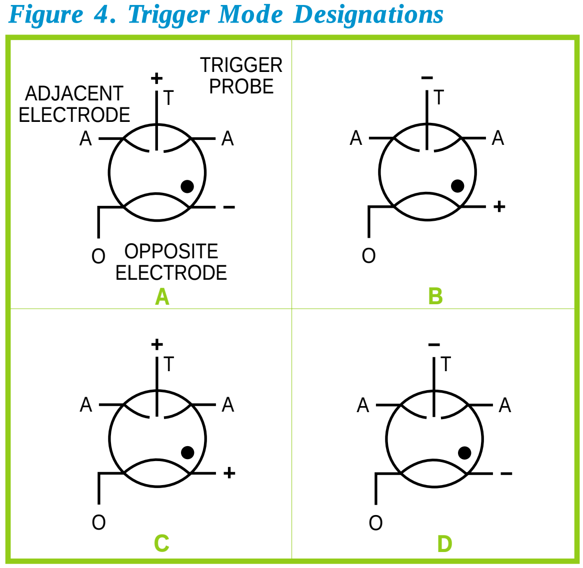


Figure 4. Trigger Mode Designations



Generally the widest operating range and the shortest delay time is obtained with Mode A operation; that is with the opposite electrode negative and the trigger electrode positive with respect to the adjacent electrode. When Mode A operation is not possible or practical, the operating voltage range is usually reduced, and the delay time and the minimum trigger voltage are substantially increased.

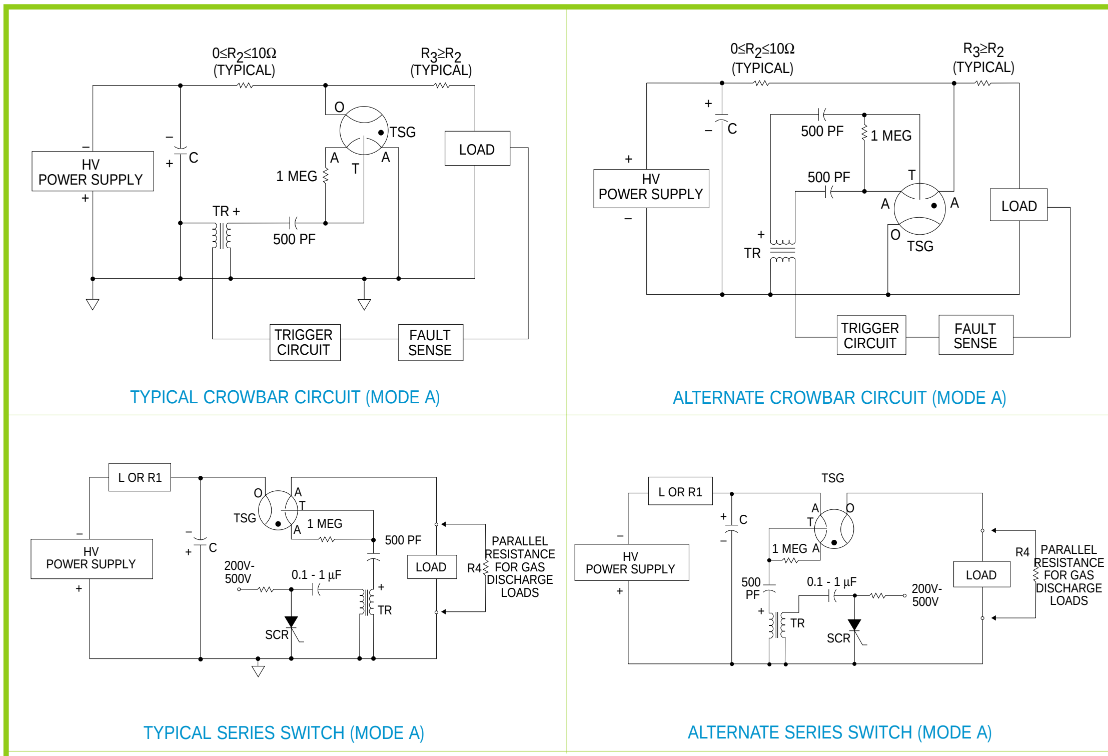
In some cases, gaps may perform adequately in Modes B or C. For example, GP-89, GP-90 and GP-91 often have the widest operating range in Mode C; i.e. the mode where both the opposite electrode and trigger electrode are positive with respect to the adjacent electrode. Operation in Mode D is not recommended for any gap.

Trigger Source Considerations

In addition to having the correct polarity, the trigger voltage pulse should typically have a rise time less than 1 microsecond, a width of 1 microsecond (minimum) and an open circuit peak amplitude greater than the specified minimum. The trigger source impedance should be less than 15 kilohms and the trigger should be decoupled as shown in the accompanying circuit diagrams (Figure 5). Trigger sources having higher impedances and shorter pulse widths may be used provided the main electrode (E-E) voltage is well above cutoff.

When used to overvolt a gas discharge tube (such as a flashlamp) a parallel load path must be provided until load conduction occurs. The impedance of the parallel load (shown in the

Figure 5.



TYPICAL CROWBAR CIRCUIT (MODE A)

ALTERNATE CROWBAR CIRCUIT (MODE A)

TYPICAL SERIES SWITCH (MODE A)

ALTERNATE SERIES SWITCH (MODE A)

A = ADJACENT ELECTRODE, O = OPPOSITE ELECTRODE, T = TRIGGER PROBE

C – ENERGY STORAGE CAPACITOR – TYPICALLY GREATER THAN 0.02 μ F

TRIGGER CIRCUIT – TR – PERKINELMER TRIGGER TRANSFORMER

R4 – CHOOSE R4 TO GIVE 1 TO 5 AMPS SPARK GAP CURRENT UNDER OPEN LOAD CONDITIONS BEFORE LOAD CONDUCTION OCCURS circuit diagrams) should allow 1 to 5 amperes of current to flow through the spark gap before load conduction takes place.

Voltage Drop and Sustaining Current

The resistive voltage drop of PerkinElmer gaps is typically about 100V. It depends primarily on the conducted charge per shot, and it decreases as the conducted charge increases. For a given number of coulombs the voltage drop is independent of peak current provided the current is sufficient to sustain gap conduction (1–5 amperes).

Recovery Time

The recovery time of gas-filled gaps is on the order of several milliseconds depending on peak current, current reversal, and voltage recharge rate. To achieve proper turnoff of the gap the discharge circuit should be underdamped with a voltage reversal of 5% or less. For a gap to recover properly after discharge, the gap current must go to zero and the voltage across the gap must be reduced to less than 30 volts. Recharging of the energy storage capacitor must take place slowly, preferably from an inductive, resonant L-C, or command charging source. Resistive charging is not optimal for short recovery time, but it may be used if the peak charging current is less than about 5 milliamperes.

Life

The end of life is normally evidenced by changes in a gap's operating characteristics due to electrode wear, vaporization, deposition of materials on the internal insulating surfaces, or fill-gas cleanup.

Energy dissipation in the gap, and hence electrode damage, can be characterized by two factors. One is the dissipation in the plasma sheaths, measured by the total coulombs per shot passed through the gap, $\int|i|dt$. In overdamped circuits, $\int|i|dt=CV$. The other factor is resistive dissipation in the electrodes and plasma, roughly measured by the parameter $\int|i|^2dt = E/R$ (amp-coulombs or joules/ohm), where $E=\frac{1}{2} CV^2 =$ joules per shot and R = total circuit resistance.

In series switching applications where repetitive pulsing occurs, average heating may also be an important factor. The two additional parameters are then the DC average current, $I_b = prr\int|i|\,dt$, and the RMS effective current, $I_p = prr\sqrt{prrE/R}$.

High Reliability Miniature Spark Gaps

PerkinElmer offers a series of small, rugged gaps designed for high reliability applications where size, switching speed and ability to withstand rugged missile environmental conditions of extreme shock, temperature and vibration are required. They are designed for switching peak currents up to 10 kA at operating voltages from 2–4 kV with reliable triggering voltage of 2 kV. Switching speeds of 70 ns with trigger pulse energies as low as 500 microjoules is typical. Life test data indicate reliable firing on many gaps after 2000 shots at 6000 amps peak current for 200 ns pulse width at 3.5 kV and load of 0.25 ohm. Physically, the miniature spark gaps measure less than 0.5 inch in both length and width, and are available with a variety of mounting and lead configurations.

PerkinElmer offers trigger transformers matched to the requirements of the miniature spark gaps. They have output voltages well above the maximum required by the switches, and are capable of sustaining the trigger-to-adjacent current during the turn-on phase of gap operation. These transformers are constructed using miniature cores, wound and potted, and are available with flying leads or pins for PC board mount.

Triggered vacuum spark gaps are ideal high-voltage switches for applications where a wide operating voltage range is desired. The low end of the operating voltage range is independent of the Static (Self) Break-down Voltage (SBV). Also, the low end of the range is normally less than 1 kilovolt when a proper trigger is applied to the gap. Contrast this with a triggered, gas-filled gap, where the lower limit of the operating voltage range is normally about 30% of SBV. It is recommended that the operating voltage not exceed 80% of SBV at the high end of the operating voltage range.

Triggered vacuum spark gaps operate in mode B or C (Figure 4) i.e., the opposite electrode is always operated positive with respect to the adjacent electrode. A trigger of either polarity is applied to the trigger electrode to initiate gap commutation and conduction.

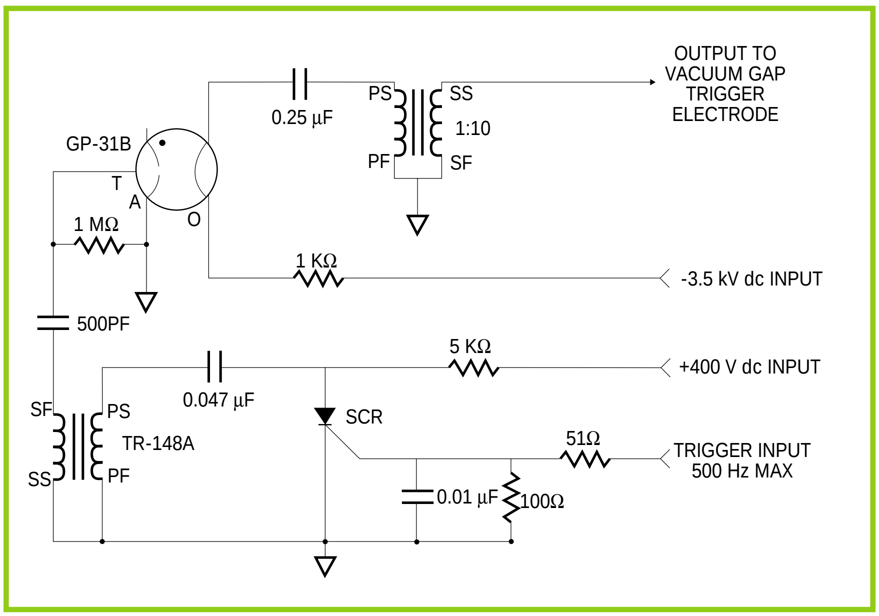
The trigger circuit should provide a 2 µsec, 12 kV (open circuit) pulse at an impedance low enough to produce a trigger current of at least 40 amperes into a short circuit. A typical vacuum gap trigger circuit using PerkinElmer transformers is shown in Figure 6. Total switching times from the trigger input to the start of main gap current flow of less than 1 µsec may be achieved when using a suitable trigger.

Crowbar Application

The crowbar circuit is one of the more popular applications of triggered vacuum spark gaps. This type of protective circuit is illustrated in Figure 7. One objective of the crowbar is to protect load circuit components from the energy contained in the power supply (and external energy storage components) during the time when faults exist in the load.

This protection is accomplished by diverting that energy through a resistive load. Because the vacuum spark gap has an extended operating range (compared to gas-filled gaps), this type of protective circuit is safely used over a wide range of power supply voltages. In addition, a burst of trigger pulses may be applied to the trigger unit to ensure that the circuit continues in its protective role by incremental reduction of the charge stored on the high-voltage storage capacitor.

Figure 6. Vacuum Gap Trigger Unit



The PerkinElmer ceramic-metal overvoltage spark gaps consist of two refractory metal electrodes in a hermetically sealed pressurized envelope. They are characterized by breakdown voltages from as low as 500 V to over 100 kV, peak current capabilities as high as 50 kA, and an arc resistance that is typically 10-20 milliohms or less.

Overvoltage gaps are most often used in crowbar circuits to divert the energy stored in a capacitor bank or inductor to protect components such as microwave tubes (klystrons, IOT's and TWT's). They are also used in pulse shaping circuits to steepen the rise time of the voltage pulse applied to a load such as a flashlamp or gas discharge laser.

Definitions

Static (Self) Breakdown Voltage (SBV): The DC voltage at which a gap breaks down when subjected to a relatively slow-rising voltage (1 kV/sec).

Dynamic Breakdown Voltage (DBV): The voltage at which a gap breaks down when subjected to a relatively fast-rising pulse (up to 1 kV/µsec).

Repetitive Pulse Breakdown Voltage (RPBV): The dynamic breakdown voltage under a repetitive pulse condition.

Impulse Ratio: The ratio of DBV to SBV, typically 1.1 to 1.5, is heavily dependent on circuit conditions such as the rise time of the applied voltage and the pulse repetition rate.

Operating Considerations

For most applications an impulse ratio approaching unity is desirable. In a RF or high di/dt environment, careful lead dress will promote the lowest impulse ratio. The gap should be placed physically near the component to be protected, and the connecting wiring should be point-to-point rather than harnessed. For small tubular gaps, a lead length under 1 inch is preferred: for larger gaps, connections should be via a wide bar or strip of foil. In addition, attention should be given to the distribution of the electric field in the vicinity of the gap—particularly at high-voltage levels—since nearby conductors and insulators can distort the field in the gap and thus alter SBV, DBV, or both. Whenever possible, gaps should be tested in the physical and electrical environment they will experience in actual service.

A gap that has been conditioned in a specific circuit will become slightly polarity-sensitive; if disconnected for any reason, the gap should be reconnected in its original orientation. The polarity of the voltage to be applied to the gap should be specified.

Single, fast-rising voltage pulses applied to a gap after an inactive period will in general promote the highest DBV, particularly when a static bias voltage has been present. DBV decreases as the time between pulses decreases (because of residual ionization), and it also decreases as the pulse rise time increases. As the pulse rise time approaches a few hundred microseconds, DBV approaches SBV.

If an overvoltage gap is used in a circuit where it is subjected to repetitive voltage pulses (a modulator, for example), its breakdown voltage will be found to be repetition rate sensitive. At low pulse repetition rates, the RPBV will approach the single-shot DBV. At repetition rates greater than 500 hertz, the RPBV approaches SBV, typically to within 10%. For repetitive pulse applications, the normal operating (standoff) voltage should be about 80% of SBV, and the extreme maximum operating voltage should be no more than 90% of SBV.

Voltage Drop and Sustaining Current

The resistive voltage drop of PerkinElmer overvoltage gaps is on the order of 100 volts during the conduction period. This drop is largely independent of the peak current as long as the current exceeds 1 to 5 amperes. When a gap is used to overvolt a gas discharge device (such as a flashlamp), a parallel load path must be provided to permit ionization of the gap and also to sustain the discharge until conduction of the gas load occurs. The impedance of the parallel load should allow a current of 1 to 5 amperes to flow through the gap.

In tightly coupled coaxial circuits (cylindrically symmetrical current flow), a gap inductance of 15 nanohenries or less may be obtained.

High-Voltage Recovery Time

The time required for a gas-filled gap to recover voltage holdoff after conduction has occurred is on the order of several milliseconds, depending on peak current, current reversal, and voltage recharge rate. For proper gap turnoff the discharge circuit should be underdamped with a voltage reversal of 5% or less. For recovery to occur the gap current must go to zero and the voltage across the gap must be less than 30 volts. The reapplication of gap voltage must take place slowly, preferably under resonant L-C or command charge conditions.

R-C charging should be avoided, but it may be used successfully if the initial charging current is less than 5 milliamperes.

Life and Energy Dissipation

The end of a gap's life is normally evidenced by a change in its breakdown voltage. This occurs because electrode material vaporizes during conduction and then condenses on the inner surface of the ceramic insulator. Fill-gas cleanup will also occur.

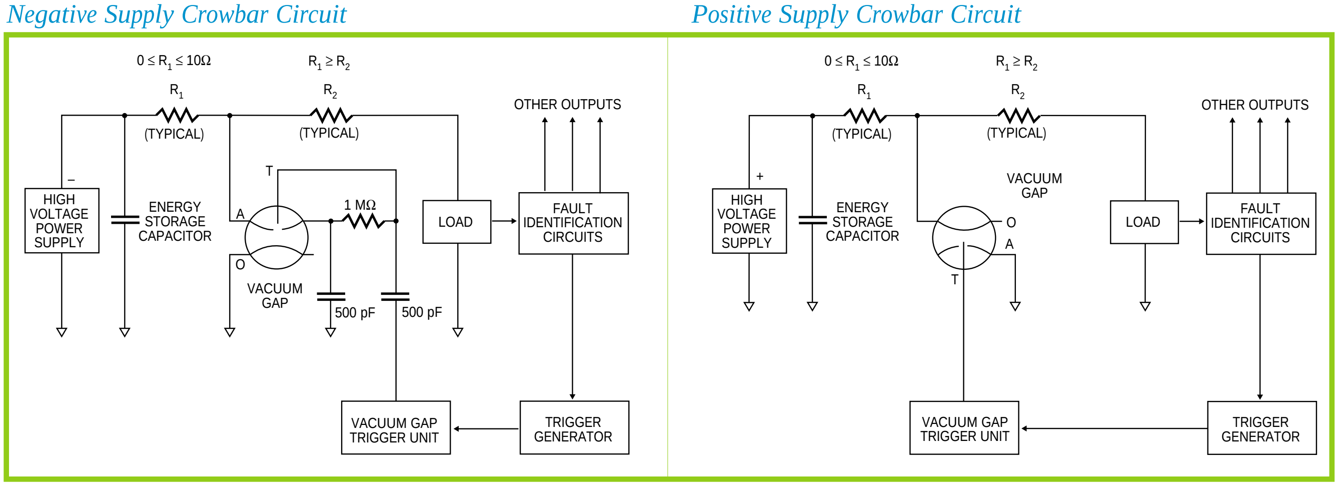
In general, life increases as the energy dissipated in the gap decreases. Often, life can be materially extended if the application will allow the insertion of a resistor in series with the gap to absorb some of the system's energy. For many applications, a resistance on the order of 100 milliohms is sufficient to reduce gap dissipation by an order of magnitude, with a corresponding increase in gap life. Because the internal processes in spark gaps are both complex and statistical in nature, no precise relationship between dissipation and life is known to exist.

Fast Switching PGP and PB Series

The PGP and PB series of overvoltage spark gaps have been specifically designed to protect critical components against damage caused by very fast high voltage transients. The breakdown time of these gaps is much faster than that of conventional overvoltage types, and they can conduct a peak fault current as high as 10 kA for PGP, 1.5 kA for PB, independently of its rate of rise. Their DBV is typically less than twice their SBV for applied voltage transients as fast as 300 kilovolts per microsecond. In single-shot protection service, PGP gaps can divert a transient energy as high as 10 joules and conduct a total charge as high as 300 millicoulombs. The small size PB series are rated at 1 joule, 50 millicoulombs, and are suitable for mounting on circuit boards and in other applications where space is restricted.

Figure 7.

Negative Supply Crowbar Circuit *Positive Supply Crowbar Circuit*



The PerkinElmer thyratrons are high energy switches capable of operation up to 20 kA and 75 kV. A wide range of standard thyratrons are offered, all constructed of rugged ceramic and metal parts. These tubes are typically used in applications such as gas laser, radar, and other modulator applications. Five basic sizes from 1 to $4^1/_2$ inches in diameter define the thyratron types in production at PerkinElmer.

Design Features

The basic thyratron is a three electrode, low pressure gas filled vacuum tube, with a thermionically emitting cathode (See Figure 8). It is a triggerable, closing only electronic switch. This basic design is used in the vast majority of applications. However, additional features have been added in order to enhance performance in certain situations.

Auxiliary Grid (TETRODE)

Basic thyratrons usually require several hundred nanoseconds to switch "on" (time measured from a standard fixed level on the rise of the trigger pulse until a fixed level is reached on the rise of the current discharge waveform). Addition of an auxiliary grid can substantially reduce the switch-on delay time (Figure 9). In actual usage, the switch-on delay time is inversely related to the current being driven in the auxiliary grid-cathode circuit until a current level is reached where little or no further reduction of the turn on delay time is realized.

The auxiliary grid may be run in the "DC primed," "pulsed," or "combination" modes. The most common mode is the "DC primed" mode. In this mode, a DC voltage is applied between the auxiliary grid (+) and the cathode (chassis ground). There is usually a series resistor to limit the DC current in the auxiliary grid circuit.

When the auxiliary grid is operated in the "pulsed" mode, a positive (with respect to the cathode) pulse is applied to the auxiliary grid which draws a current that can be up to an order of magnitude greater than would be the case for the "DC primed" example. The pulse is applied to the auxiliary grid about 1 microsecond prior to pulsing the control grid. The auxiliary grid pulse may end at any time after the control grid pulse has been on for at least 1 microsecond.

Operating the auxiliary grid in the "combination" mode combines both "DC primed" and "pulsed" modes. In all cases, gas is ionized between the cathode and the auxiliary grid when the control grid is pulsed.

Therefore, the time required to ionize the gas and establish electron flow to the auxiliary grid level is already past, leaving only the time required to spread the plasma from the auxiliary grid level through the control grid level. The total time from application of the control grid pulse to the start of main discharge current flow is substantially reduced.

Liquid Cooling

For several reasons, it is desirable for the tube's electrodes to achieve at least certain minimum temperatures during operation. However, where a high anode heating factor and/or high RMS current is required in the application, excessive heat

Figure 8. Typical thyratron schematic

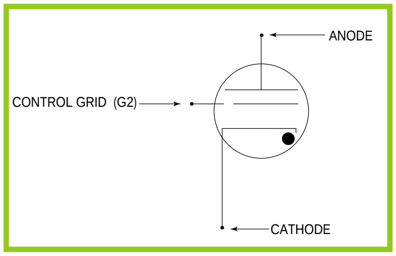
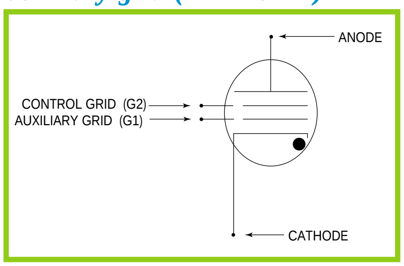


Figure 9. Thyratron with auxiliary grid (TETRODE)



may develop. In these cases liquid cooling the thyratron may allow operation at those otherwise unacceptable conditions. If liquid cooling is not possible or sufficient, the next larger tube size is recommended.

Two methods of liquid cooling the tube are in general use, immersion and circulation. In some cases, the desired performance may be achieved by simply immersing the tube in a coolant bath or inlet temperature not to exceed 30°C. In demanding situations it is desirable to circulate the liquid toward certain tube "hot spots" to achieve a higher degree of cooling. To this end, PerkinElmer offers thyratrons with cooling pipes attached to the anode and/or grid area to allow direct circulation of liquid for cooling.

Hollow Anode

Basic thyratrons are much like normal vacuum tubes in that they have a heated cathode and a relatively cool flat, solid anode. The flat, solid anode is not a good electron emitter and therefore the tube will act like a diode when a reverse voltage (i.e., negative with respect to the cathode) is applied to the anode (it will not conduct in the reverse direction). This characteristic is desirable in most instances. However, in some underdamped pulse circuits, the reverse (negative) voltage on the flat, solid anode becomes high enough to cause conduction for one or more reverse half-cycles of the discharge current waveform. In those instances, anode damage is caused by cathode spot formation. A cathode spot is a very localized molten spot that is high enough in temperature to emit electrons. Unfortunately, the temperature of this spot is usually high enough to liquefy the anode material and evaporate it from the anode surface. Not only does this result in the loss of anode material, but it usually results in deposition of some of that material on the ceramic insulators of the tube. When the insulators become locally conductive near the very high electric field space that exists between the anode and the grid, arcing from anode to grid through that locally conductive layer usually results and further leads to deteriorating holdoff performance of the tube.

To improve electron emission of the anode during reverse half cycles, holes are made in the anode's flat face that lead to a cavity behind that face. A significant number of electrons enter those holes on the forward half cycle of the tube's conduction. These electrons are available to contribute to reverse current flow during the reverse half-cycles of the discharge waveform since many have not yet had time to become trapped within the metal walls of the anode. PerkinElmer hollow anode thyratrons are usually rated to conduct in the reverse direction up to 40% of the peak current that was conducted on the immediately previous positive half cycle of the current discharge waveform. Higher reverse current levels are achievable at the expense of some damage to the anode. However, since the electron emission predominates from cathode spots that are formed within the holes or cavity of the anode, the metal vapor by products of those spots do not coat the ceramic insulator. Hollow anode thyratrons do "wear" at a higher rate as the magnitude of reverse current increases, but they do not generally exhibit the rapidly deteriorating holdoff capacity of solid anode tubes.

Grounded Grid

In applications with extremely high peak current and rate of rise of current, a grounded grid thyratron is the best choice. The thermionic cathode of the grounded grid thyratron only has to inject enough electrons into the space between the grid baffle and the grid itself to start the hollow cathode process that is described in most "pseudospark" switch literature. Almost all of the electrons that are involved in the grid-anode discharge are generated at cathode spots in the hollow cathode area that is located in the grid slots and at the back surface of the grid away from the grid face (the large flat area that directly faces the anode). Proper design of the slot area, grid material, and spacing of the grid from the anode will allow extremely high peak currents at extremely short risetimes while minimizing grid wear. Currently grounded grid thyratrons all have had solid, flat anodes. Anode and grid wear due to cathode spots has been the life-limiting factor in the grounded grid tube. See the individual tube's data sheet for more specific information.

Low Inductance

PerkinElmer's low inductance tubes are designed to fit into very tight discharge loop circuits. Of necessity, this generally means that they have an overall seated height that is significantly shorter

than the length of a tube that has similar electrical parameters but one expected to operate in a circuit with more inductance.

In essence, the low inductance tubes are just "normal" thyratrons that have been severely repackaged to fit into the smallest height circuit that is reasonably possible.

Because of the significant overall height reduction in the thyratrons, the length of the high voltage stand-off ceramics may not be sufficient for operation at normal ambient atmospheric conditions. Under normal conditions, 10 kV per inch may be applied across the ceramics. Industry standard derating data should be consulted for the voltage that may be applied to the ceramic under other conditions. Most users of low inductance tubes usually find it necessary to operate those tubes in pressurized alternative gases or dielectric liquids.

Current Derating Curve

PerkinElmer data sheets will generally list the maximum peak current capability of the individual thyratron under a section titled "Absolute Ratings." That peak current is usually specified at a reasonably short duration current pulse width such as 250 nsec and it generally remains the maximum peak current rating for pulses shorter than the pulse width that is listed. However, as the pulse width is increased in time, the peak current limit must be reduced. The formula for rating the peak current capability of a thyratron at wider pulse widths is as follows:

$$i_{bt}=i_{b3}(3/t_p)^{1/2}$$

where i_{b3} is the peak current rating at the pulse width listed for the absolute maximum limit; tp is the pulse width of interest (in µS); ibt is the peak current rating at the pulse width of interest.

Thyratron Lines

1 inch thyratrons: The typical thyratron in this line is able to switch 100 A at up to 8 kV. “Low power” pulsers and Pockels cell drivers are typical of the applications for these tubes.

$1^1/_2$ inch thyratrons: The typical thyratron in this line is able to switch 350 A at up to 16 kV. Many mechanical and a few electrical variations of the basic tube design are readily available. Typical applications are in Pockels cell drivers, radar transmitters, and portable gas lasers.

2 inch thyratrons: These thyratrons are able to switch 500 A at up to 20 kV. Several different configurations are offered in this line, including a grounded grid model. Typical applications range from the standard radar transmitters to lasers and laboratory analytical equipment.

3 inch thyratrons: Switching 1500 A at up to 35 kV is typical for these thyratrons. Multi-gap, grounded grid, various gas fills, liquid cooled, and hollow anode versions of the basic thyratron are also offered. Some of these tubes have been operated at over 10 kA peak current (250 nS pulse width) at up to 70 kV with reverse current capability of 40%. PerkinElmer’s widest variety of physical shapes and sizes, as well as electrical performance, is found within the 3 inch line of thyratrons. These tubes have been used in a very wide variety of applications from radar transmitters, through medical equipment and lasers.

$4^1/_2$ inch thyratrons: The typical tube in this line easily switches 5 kA at up to 40 kV. As with the 3 inch line, there are standard tubes in this line that have multi-gaps (up to 3), hollow anodes, large area cathodes, liquid cooling, and various gas fills. Several of these tubes are capable of switching up to 20 kA (250 nS pulse width) and a few will do that at up to 75 kV.

Thyratron Drivers

PerkinElmer offers the TM-27 and TM-29 drivers designed to supply trigger voltage to the thyratron at up to 2000 Hz. They accept an external trigger or can be set to a fixed rate.

The PerkinElmer Miamisburg facility located in Miamisburg, Ohio is a unique research, development and production operation that has an extraordinary resource pool of scientists, engineers and technical personnel. They are an internationally recognized facility with expertise in Electro-Explosive and Laser-Initiated ordnance technology, and design, development and production of world class detonator components and systems.

Explosive Blending

PerkinElmer has the expertise and the fully integrated facilities necessary to safely manufacture explosive powders for ignitors, actuators, detonators, and EFI's. These energetic blends provide improved performance, safety, and reliability over available market alternatives. The superiority of PerkinElmer's products is a result of our unique blending capabilities that guarantee purity and reproducibility. PerkinElmer has a long history of providing fine particle HNS-IV for use in EBW and EFI detonator systems. Currently, PerkinElmer is one of a very limited number of producers of Titanium Subhydride Potassium Perchlorate, which is a static insensitive pyrotechnic. The material is unique in that no special handling requirements are necessary during subsequent component manufacturing. This pyrotechnic, along with similar products, has been manufactured by PerkinElmer for over two decades.

Explosive Loading and Powder Pressing

Our technicians possess expertise in the areas essential to explosive component development and manufacturing: precision weighing and loading, and explosive powder evaluation. Based on their in-depth understanding of explosive density and particle morphology, PerkinElmer's scientists and engineers have been able to develop explosive designs capable of achieving optimum and repeatable performance by matching the input bridge element or the laser input to the explosive characteristics.

Glass-Ceramic Technology

At the heart of many ignitor, detonator, and actuator designs are the state-of-the-art technology, facilities, and equipment necessary to fabricate glass-ceramic, hermetic headers and feedthroughs. PerkinElmer scientists and engineers have developed the technology to flow the glass into a shell, develop the glass-ceramic strength, and machine the glass-ceramic for various DOE and DoD development and production programs.

Exploding Foil Initiation and Chip Slapper Technology

The PerkinElmer scientists and engineers possess extensive experience in the design, development, manufacture, and testing of Exploding Foil Initiation (EFI) detonators. Their experience combines to provide all the capabilities necessary to operate a fully integrated detonator manufacturing facility. Their extensive research of performance characteristics and the interrelationships between parameters has allowed PerkinElmer to develop an in-depth understanding of slapper detonator technology. As a result, PerkinElmer is capable of providing custom configured slapper detonators based on superior precision timing technology. Research pertaining to the basic understanding of detonator performance is an on-going endeavor in the effort to continually improve detonator designs.

PerkinElmer currently manufacturers Blue Chip™ Detonators ("Chip Slapper" detonators with HNS–IV explosive powder) using industry standard TO-5 headers with 2 and 6 pin configurations, surface mount contact and detonators attached to flexible tape strip lines.

Laser Initiator and Detonator Technology

Our engineering and manufacturing personnel have knowledge and experience in the design and development of Laser Initiators and Detonators. Our scientists have designed and fabricated many types of optical feed through devices including: "Fiber Pigtail", "Window", "Fiber Pin" and ball lens designs. One of the keys to the laser ignited explosive design is the technology of sealing an optical feed-through into a metallic shell. Connector style units, pig tail units, and right angle feed-through designs have all been fabricated utilizing glass-ceramic technology. Optical transmission values are typically greater than 80%. The effects of thermal conductivity on the ignition process are routinely determined and factored into the design parameters of each device.

PerkinElmer Optoelectronics has the unique capability of providing a complete laser ordnance system (diodes, drive electronics, and ordnance devices) by designing our laser ordnance devices to interface with high power InGaAs laser diodes and electronic sequencer systems manufactured by our Optoelectronics operations in Vaudreuil, Quebec and Covina, California.

Explosive Ignition Technology

In addition to the above capabilities, PerkinElmer has access to an extensive materials analysis facility with state-of-the-art instrumentation in surface science, metallurgy, thermal analysis, and x-ray diffraction. PerkinElmer's leadership in the science and technology of its explosive components is well known throughout the technical community. It is PerkinElmer's goal to maintain and build on this capability through constant technology improvements.

Thermite Technology

PerkinElmer's ordnance technology includes the capability to manufacture thermite components. Thermites are blends of metals and metal oxides that burn at extremely high temperatures, while producing very little gas emission. Our scientists and engineers have developed hot pressing and plasma forming technologies to support the manufacture of thermite components, which can be molded and machined in a myriad of sizes and shapes. Thermite material can also be deposited on surfaces of other materials as thin as two one-hundredths of an inch, and can withstand extreme environmental conditions.

Various thermite components can be formed for specialized applications as torches, heat sources and destruct devices. The use of thermite material as a "torch" is especially applicable for remote or portable welding applications when normal gases or electricity are not available. In this mode, it may also be used for the cutting or penetration of metals, such as emergency escape systems to breech locked portals. When confined in specialized enclosures, thermite material may be utilized as a fast acting, high intensity heat source.

One of the more recent and important uses of thermite material is its application as a destruct device to maintain the security of sensitive or classified material. Thermites can be used to disable critical components without collateral damage in a variety of systems (e.g., computers, military equipment and courier attaché cases). The extreme heat destroys electrical components and de-poles magnetic material so residual information cannot be re-constructed.

Advanced Joining Processes

PerkinElmer scientists have developed several specialized methods for joining metals. These advanced processes include laser welding, electron beam welding, resistance welding, and diffusion bonding. High strength welding is required for components and systems that function under high stress situations, such as velocity, rotation, and abrupt start-stop conditions.

PerkinElmer's laser (Nd:YAG) welding produces very small, precisely positioned welds. This technique requires the lowest energy input of fusion welding processes and results in minimal temperature rise to the surrounding explosive materials.

Electron beam welding is a high power density process that can provide welds with a depth-to-width ratio as high as 20:1. Electron beam welding is versatile and can be used on very small items only a few thousandths of an inch thick or on stainless steel four inches thick.

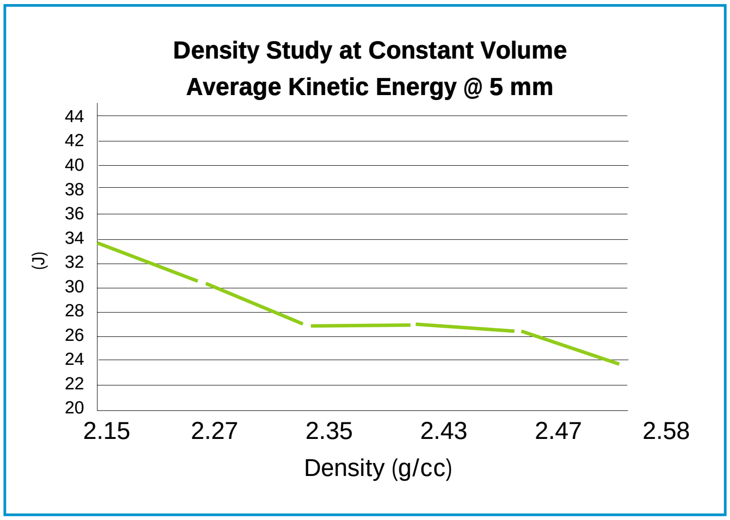
Resistance welding has a specialized dimension of its own, expressed in weld diameters of thousandths and ten thousandths of an inch. It is ideal for welding extremely small components and comes with the technological refinements of inert gas shielding, thorium tungsten electrodes, miniaturized tooling, and process characterization.

Diffusion bonding is a solid state process used for the joining of components that require high reliability performance. A typical bond is produced at 5500 psi with a weld temperature of 600°F in three minutes.

PerkinElmer's technical staff has also developed data acquisition systems as a form of quality control for most of its welding processes. These computer based systems provide a significant time saving over destructive metallographic analysis.

Diagnostic, Destructive and Environmental Testing

PerkinElmer scientists and engineers have developed world class techniques to measure the performance of energetic devices. Test facilities encompass the entire range of temperature, vibration and shock environments required for military, aerospace, and industrial applications. In addition, a special facility for VISAR testing, based upon optical interferometer techniques,



allows for the highly accurate measurement of detonator flyer velocity as a function of distance.

The capability exists to evaluate real-time analysis of products that function in the millionths-to-billionths of a second range or analyze the design of materials and mechanical devices that function under high stress conditions. These testing technologies can determine product life under static or varying environmental conditions, the compatibility of materials, and the design life of products. One-of-a-kind and world class are precise descriptions of PerkinElmer's diagnostic and destructive product test facilities, which include large test cells, single unit testing facilities, high-speed camera capability, and real-time statistical control for dynamic testing. PerkinElmer has improved the traditional capabilities of mirror camera recording of dynamic events with multi-angle photography and improved data reduction capacity.

Environmental testing includes both thermal and mechanical capabilities to simulate transportation, storage, and use of products. PerkinElmer can simulate thermal shock, thermal cycling and thermal storage at a wide range of continuous or changing temperatures. Mechanical testing

includes a wide range of capabilities, and data collection and analysis is backed up by ancillary experience in tester design. These capabilities encompass vibration, hostile shock, impact shock, and spin testing.

Pyrotechnic Materials and Pyrovalve Technology

PerkinElmer specializes in the blending and characterization of pyrotechnic mixtures. A unique material, Titanium Sub-Hydride Potassium Perchlorate which was developed by the Sandia National Laboratory for specific DOE applications, is now available for commercial applications. This material is a static insensitive pyrotechnic, and has been very well characterized.

PerkinElmer has the experience to design and manufacture small safe pyrotechnic devices to fit a variety of specific applications. By using insensitive titanium sub-hydride potassium perchlorate material, the devices; i.e. ignitors, squibs or actuators, are electrostatically safe, have low ignition energy requirements, are reliable and exhibit high pressure integrity after use.

PerkinElmer scientists have developed a Kinetic Energy Device for use in measuring the output of a pyrotechnic squib or actuator used in pyrovalve applications. This test uses a matched mass piston to receive the energy from the squib. The motion of the piston is monitored at the flight distance of interest and the equations of motion are used to establish the Kinetic Energy of the piston and the theoretical gas driving pressure. Experiments have shown good correlation between calculated pressure data and measured data.

Electronic Safe, Arm and Fire Systems

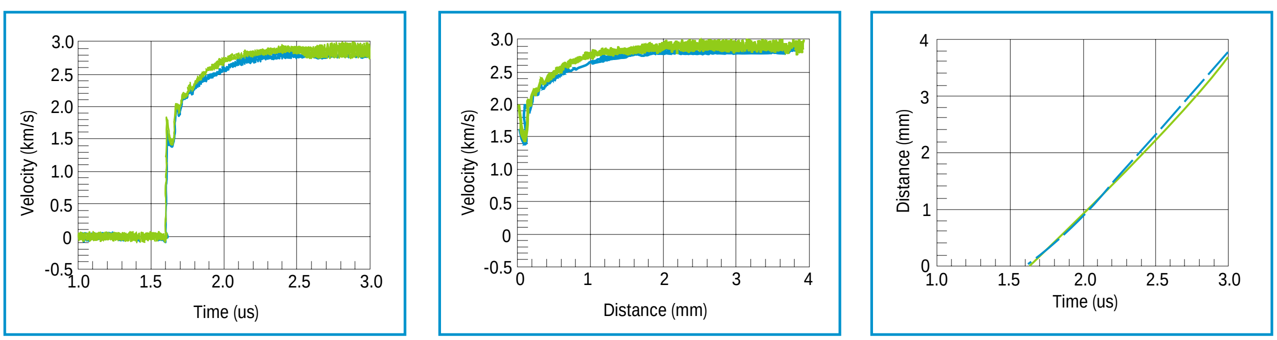
PerkinElmer is on the leading edge of all technologies related to components for Electronic Safe, Arm and Fire (ESAF) systems. This includes the design and manufacture of commercial-off-the-shelf (COTS) components such as Triggered Spark Gaps, Trigger Transformers, Power Supplies, Energetic Material, and Exploding Foil Initiator (EFI) or Chip Slapper devices.

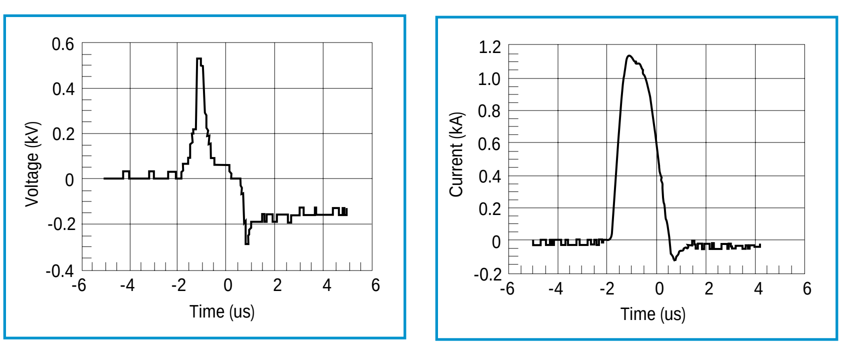
With a team of electronic, explosive and mechanical design engineers formerly dedicated to DOE weapons activities, PerkinElmer Optoelectronics has combined these commercial components in a new, modular, state-of-the-art, all electronic design to replace older, mechanical based safe and arm systems. This new design has numerous advantages including:

- Low cost micromachined accelerometers that permit a more accurate measurement of missile safe separation distance.
- In-line explosive initiation systems employing Chip Slapper detonators and insensitive secondary explosives.
- Enhanced modularity for improved multi-missile system affordability.
- Increased ease of testability due to "built-in-tests" and simple disconnect/reconnect of all the explosive components from the electronics package.
- Independent, redundant static and dynamic safety features.

The basic design is easily adaptable to most common missile systems. Low cost custom configurations based on common module designs are available on request.

VISAR Shows the HVD has Velocity for Long Distance





Distance	=	1.5 mm
Vel_Dist	=	2.751 km/s
	=	2.851 km/s
T_Dist	=	3.452 us
	=	3.429 us
T_Move	=	2.823 us
	=	2.822 us
T_Burst	=	460 ns
V_Burst	=	531.3 V
I_Burst	=	1.129 kA
I_Peak	=	1.139 kA
VOLTAGE	=	2323.54
DELAY	=	-1.45e-5
SERIAL	=	7
VPF1	=	698
VPF2	=	-1559

CUSTOMER SERVICE: YOUR NEEDS ARE OUR NEEDS

At the heart of our operation is a team of dedicated and responsive PerkinElmer employees, highlighted by our Customer Service personnel.

This experienced staff stands ready to provide you with immediate, helpful service, answering any question you may have about our products, our services, and our ordering procedures.

You can contact the Customer Service Department directly by calling **978-745-3200** or our toll-free number, **800-950-3441**, from 8:00 a.m. to 4:30 p.m. (EST). Or send us a fax at **978-745-0894**.

Located in Salem, Massachusetts, the Customer Service Department serves PerkinElmer Optoelectronics–Salem customers, allowing you to:

- Place a Product Order — in a quick and efficient manner.
- Obtain Sales Center Information — about one of the locations in our worldwide network of offices, distributors and representatives.
- Order Product Literature — including technical literature that details the features, specifications and performance of our products and services.
- Procure Written Quotations — for any product or service, standard or custom.
- Receive Engineering Assistance — through product engineers and design teams who can help you with everything from single components to complete electro-optical systems.
- Obtain Manufacturing Information — concerning our quality standards, procedures and certification processes.