Application Information
for
SG-Series Spark-Gap Switches

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SG-series spark-gap switches are engineered for dependable service with minimal maintenance. This guide gives recommended installation and operation instructions for representative applications. Please consult us for advice on applications not discussed here. We provide complete engineering and design services, including turn-key construction of customized pulsed power systems, on a contract basis.

> ***IMPORTANT SAFETY ADVICE***
>
> *Please observe all prudent safety precautions with high-voltage circuitry. Careful grounding and shielding will minimize hazards and safety interlocks should be employed at all times. Remember that a capacitor can re-acquire a LETHAL charge following discharge because of dielectric relaxation. Use shorting straps when servicing high-voltage equipment and assume nothing is at ground potential!*

Introduction

Gas-filled spark gaps satisfy a range of plasma-closure switching requirements involving capacitive discharge circuits. Series SG switches manufactured by R. E. Beverly III and Associates are designed for use in low-inductance (e.g., strip-line), fast-pulse systems where large peak currents (~1–500 kA) and high voltages (2.5–75 kV) are commuted. Although nominally designed for single-pulse operation, repetition rates in excess of 100 Hz are possible for decreased charge-transfer rates. Modular construction allows different configurations to be rapidly assembled from off-the-shelf components. Three basic switch types are available: (i) passive, (ii) electrically triggered, and (iii) laser triggered. Passive switches have only two electrodes and operate spontaneously when the applied voltage exceeds the self-breakdown voltage. Electrically triggered switches utilize three electrodes and employ an external trigger generator to initiate breakdown— we manufacture both *trigatron* and field-distortion switches. Laser triggered switches consist of two electrodes and a lens that focuses laser radiation onto an on-axis, mid-plane point between these electrodes; the laser-generated spark initiates breakdown.

Pulsed-power applications for SG-series switches generally fall into two broad categories:

1. Series switches, where stored energy is discharged rapidly into a load. Typical loads include flashlamps, gas lasers, accelerators, exploding wires, plasma pinches, x-ray generators, etc.

2. Protective switches, where the gap is used to short circuit or *crowbar* energy-storage devices thereby protecting other circuit elements from damage due to over-voltage and/or over-current.

Although they are simple in design, spark-gap switches must be installed and operated properly for best results. This application guide gives information on switch construction, operating characteristics, electrical connections, gas-supply requirements, replacement parts, and our warranty. Detailed switch specifications and ratings are given in a separate brochure. For further technical information, please consult the references listed in the bibliography.

Construction

Series SG switches are designed for reliability and durability. Sintered tungsten-alloy electrodes ensure long life and low probability for misfire or prefire. The translucent polycarbonate insulator makes firing easily and safely visible without UV hazard. The top and bottom plates are 6061 aluminum alloy; the bolt circles are identically dimensioned and located for easy attachment of conductors. Buna-N (Nitrile Elastomer) O-rings seal the top and bottom plates and trigger plug (trigatron models).

For the field-distortion models, the trigger ring is self-locating and self-centering using either plastic dowel pins or ceramic standoffs and a brass rod serves as electrical feed-through. The gas fittings are made of nylon or polypropylene, depending upon the model, and all fasteners are nylon or stainless steel. Models are offered with English or metric fasteners (-E or -M suffix, respectively). All components, including the trigger plug for the trigatron models, the trigger ring for the field-distortion models, and the lens for the laser triggered models, are readily replaceable and the entire switch can be disassembled for inspection and cleaning using ordinary tools.

Operating Characteristics

Trigatron. The trigatron has found wide application in the pulsed power community as a demand-triggered, high-voltage switch whose self-breakdown voltage can be easily changed over a wide range by adjustment of the internal gas pressure. These simple devices employ two main discharge electrodes, called the opposite (O) and adjacent (A) electrodes, and an insulated trigger pin (T) that is usually flush with or slightly recessed below the surface of the adjacent electrode. The internal gas acts as an insulator until an external trigger pulse initiates breakdown between the trigger pin, adjacent electrode, and/or opposite electrode. The two main electrodes carry the current once the main gap becomes fully conductive. There is no trigger pin in the passive models and self-breakdown occurs when the gap voltage exceeds the self-breakdown voltage. Trigatron switches are the least expensive models to purchase and the simplest to install and operate.

Field-Distortion Switches. Both main electrodes (M) in the field-distortion switch are identical and a trigger ring is suspended at the mid-plane between these electrodes. Proper biasing of the trigger ring ensures that the static potential of this electrode is exactly one half of the potential across the main gap, i.e., prior to triggering. When a fast-rise trigger pulse is applied to this ring, the local electric field is severely distorted which induces avalanche ionization of the gas and electrical breakdown of the main gap. Although more complicated to configure and install, field-distortion switches offer the fastest breakdown time and lowest jitter for our electrically triggered models.

Laser Triggered Switches. These models rely upon a laser-generated spark to initiate breakdown. A spark is produced when the local electric field within the focal volume exceeds the minimum required for avalanche ionization. Streamers from the main electrodes to this spark cause complete breakdown of the gas within the gap and closure of the switch. Laser trigger switches offer very precise triggering and the lowest jitter of all of our models.

The important parameters in this discussion are defined as follows:

I_p — **Peak Discharge Current**, the maximum discharge current that flows through the main gap.

Q — **Charge Transfer**, the total charge transferred by the switch; for a series-discharge circuit (non-oscillatory) with capacitive energy storage, $Q = CV_g$.

t_{bd} — **Breakdown Time**, the time between arrival of the voltage pulse at the trigger electrode and main gap conduction, often defined as the time at which the instantaneous current $I(t)$ is a small fraction of the peak current in the main circuit, e.g, $I(t_{bd}) = 0.1I_p$; minimum breakdown time is obtained when the switch is operated in the heteropolar mode, when the main-gap voltage V_g is close to the self-breakdown voltage V_{sb}, and when a fast rising trigger pulse is used. For over-volted passive gaps, t_{bd} depends primarily upon dV_g/dt. For laser triggered switches, t_{bd} is defined by the time between arrival of the laser pulse at the switch and main gap conduction. For electrically triggered switches, $t_{bd} \approx 100$ ns at the lowest operating voltage and decreases rapidly to ≤ 20 ns as $V_g \rightarrow V_{sb}$. For laser triggered switches $t_{bd} \leq 10$ ns.

E_{laser} — **Laser Energy**, for laser triggering, the minimum energy required to reliably initiate breakdown.

τ_{laser} — **Laser Pulse Width**, for laser triggering, the maximum pulse width recommended to achieve the specified jitter.

σ_{bd} — **Jitter**, the statistical pulse-to-pulse difference in t_{bd}, defined here as one standard deviation.

V_{g} — **Main Gap Voltage**, the potential between the two main electrodes prior to breakdown.

V_{min} — **Minimum Operating Voltage**, the minimum voltage across the main gap that assures firing using a standard triggering arrangement; operation below this voltage is unreliable and is not recommended.

V_{op} — **Recommended Operating Voltage**, the value of V_{g} recommended for most reliable operation with minimum delay time and jitter, typically 60-80% of V_{sb}; operating at a higher voltage increases the statistical likelihood of a prefire or misfire, especially during repetitive operation, while operating with $V_{\text{g}} << V_{\text{op}}$ will result in excessively long breakdown times.

V_{sb} — **Self-Breakdown Voltage**, the voltage across the main gap at which there is a 50% probability that self breakdown will occur; the gas fill, internal pressure, and electrode separation determine this value. The self-breakdown voltage will be strongly influenced by the time between discharges (see the discussion below on **Recovery Time**). Passive gaps operated in a repetitive mode, in particular, will exhibit premature breakdown at $V_{\text{g}} < V_{\text{sb}}$.

V_{t} — **Trigger Voltage**, peak voltage appearing on the trigger electrode just prior to breakdown.

V_{t}^{*} — **Critical Trigger Voltage** (trigatron switches only), trigger voltage that produces simultaneous breakdown to the adjacent and opposite electrodes, which concomitantly minimizes breakdown time and jitter. The critical trigger voltage depends upon the main gap voltage and switch geometry as discussed below.

Electrically triggered spark gaps are generally characterized by an arc resistance of ~1 mΩ, a breakdown time ~10–100 ns, a jitter ~10 ns, a self-inductance <20–45 nH, and a life expectancy of ~10^3–10^6 shots. Significant improvements in t_{bd} and σ_{bd} are possible with laser triggered switches. R. E. Beverly III and Associates manufactures trigatron, field-distortion, and laser switches that offer working voltage ranges from 2.5 to 75 kV, peak current ranges from ~1 to >500 kA, and repetition rates to 100 Hz. Current pulse widths are dependent upon the user's circuit and are typically in the range of 100 ns to ~10 µs. Custom switch development is available upon request.

Triggering of Trigatron Switches. In the conventional trigatron circuit and as recommended here, the opposite electrode is at high potential and the adjacent electrode is at ground potential. A trigger pulse with peak voltage V_{t} is applied to this pin in the presence of the main gap voltage V_{g}. Switch closure involves two gaps, the trigger gap d_{t} between the trigger pin and the adjacent electrode, and the main gap d_{g} between the opposite and adjacent electrodes. For heteropolar operation, i.e., V_{t} and V_{g} are of opposite polarity, the mean electric field between the trigger pin and adjacent electrode and between the high-potential opposite electrode and the trigger pin are

$$E_t = V_t / d_t \qquad \textbf{(1a)}$$

and

$$E_g = (V_g - V_t) / (d_g + h), \qquad \textbf{(1b)}$$

where h is the pin recess distance. Two discharge initiation and switch closure mechanisms are possible: (i) if $|E_{\text{t}}| > |E_{\text{g}}|$, then the trigger pulse first causes breakdown to the adjacent electrode (BAE) and the resulting UV radiation and plasma provide a source of ionization leading to discharge across the main gap, or (ii) if $|E_{\text{t}}| < |E_{\text{g}}|$, then the trigger pulse first forms breakdown streamers directly to the opposite electrode (BOE) and the resulting ionization density, which is driven by the applied field, avalanches until the arc channel forms, the resistance across the main gap drops abruptly, and the switch closes. There is general agreement in the literature that operation in the purely BAE mode results in a longer breakdown time and excessive jitter.

Optimal results are obtained with simultaneous BAE and BOE initiation using the critical trigger voltage V_t^*, given by

$$V_t^* / V_g = -d_t / (d_g + h - d_t) \qquad \textbf{(2)}$$

for heteropolar operation. Hence, for $|V_t| > |V_t^*|$, BAE operation will occur first while for $|V_t| < |V_t^*|$, BOE will happen first.

Triggering of Field-Distortion Switches. Prior to triggering, the trigger ring must not be allowed to float at some uncontrolled potential but rather must be at a potential that is exactly one half of the voltage difference between the main electrodes. The polarity of the trigger pulse must be chosen to induce the maximum field gradient, e.g., if the high-voltage side of the switch is at positive potential and the other side is at ground potential, then the trigger pulse should be negative potential. The trigger circuit must be properly decoupled and biased as described below in **Representative Circuits**.

Triggering of Laser Switches. Using excimer or nitrogen lasers, for example, a peak intensity at focus $>10^{12}$ W/cm^2 is required to initiate a laser generated spark and trigger breakdown. Light enters the switch through an on-axis aperture of 0.670 inches (17 mm). The focusing lens (supplied) is integral with the switch and is selected for use with the customer's laser. To protect the lens from discharge vapor, the focusing chamber is pressurized and gas flow from this chamber through the hole in the main electrode, into the switch interior, and then exits through two tube fittings in the insulator. Generally speaking, visible or UV lasers with a pulse energy ~1 mJ and a pulse width ≤ 30 ns will reliably trigger these switches. For extremely short-pulse lasers such as those operating in the femotosecond regime, the switch can be triggered with an extremely small energy: $\tau_{\text{laser}} \sim 10^{-15}$ s, $E_{\text{laser}} \sim 1\ \mu$J.

Trigger Generator Requirements. Triggering requirements for the electrically initiated models demand a fast pulse having a peak voltage $>|V_g|/3$, a rise time ~1 kV/ns (field-distortion) or ~0.1 kV/ns (trigatron), and an energy >5 mJ. Our model PG-103B trigger generator is specifically designed for use with series-SG switches and can be configured to simultaneously control up to four switches. A trigger transformer is provided for each switch and the trigger generator may be located up to 19 feet (6 meters) away. Any channel may be disconnected without harm to the unit. The peak voltage is set at the factory and is optimized for the particular switch model ordered, although it may be readjusted using an internal potentiometer. Single pulse or repetitive operation (externally or internally clocked) is possible. A recharge command signal is provided for synchronizing and controlling an external constant-power charging supply. An adjustable delay (0.04–14 ms) allows time for the switch to recover before voltage is reapplied to the energy-storage capacitors during the subsequent recharge cycle. This feature is particularly important during repetitive operation at high frequencies. Complete details of the PG-103B are given in a separate brochure.

Voltage Drop. The resistive voltage drop is typically 130-370 V and is dependent upon Q and the gas fill. For a fixed value of Q, the voltage drop is independent of I_p, provided that there is sufficient current to sustain conduction (>10 A).

Recovery Time. The gap recovery time depends upon I_p, Q, and the gas type, pressure, and flow rate. Minimum recovery times are only obtained when the discharge waveform is critically damped or over-damped; recovery will be prolonged for discharges with significant voltage reversal. Recharging of the energy-storage capacitor should occur slowly, preferably by means of an inductive or resonant L-C charging system. For repetitive operation, best results are obtained using a command charging source that delays recharging for a few milliseconds following each discharge. Constant power supplies are available from several vendors that satisfy these requirements. These HV supplies should be connected directly to the energy-storage capacitor(s) without charging resistors. A fully discharged capacitor represents a short circuit to a constant-power supply and the supply begins the charge cycle in constant-current mode. As charge flows to the capacitor, the supply senses when the current drops below the limiting value and changes to constant-voltage mode. The set-point charging voltage is maintained until the subsequent switch closure-capacitor discharge and the charge cycle begins afresh.

Life Expectancy. Energy losses in the switch are due to three mechanisms: (i) plasma sheath dissipation including various electrode sputtering phenomena, (ii) heating of the gas column in the spark and associated radiative losses, and (iii) resistive (Joule) heating in the bulk electrode material. There is unfortunately no precise method for predicting life expectancy since operating conditions vary widely. Under maximum rated operating conditions, typical life expectancies are 5,000 to 20,000 shots. Life expectancies in excess of 100,000 shots can be realized under derated operating conditions. Periodic maintenance by the user is necessary to achieve these limits. Although we can provide estimates for user-specific conditions, we recommend that the user perform lifetime tests for critical applications.

Life expectancy is primarily limited by erosion of the main electrodes due to mechanism (i) and is therefore dependent upon total accumulated charge transfer. For the trigatron models, erosion of the trigger pin will lead to erratic operation. In most circumstances, the life of the trigger plug will be shorter than the life of the main electrodes; however, the trigger plug can be easily replaced in the field without disassembly of the entire switch. Intense radiation from the spark [mechanism (ii)] causes ablation of insulator material. Sputtering of the electrodes also adds impurities to the internal gas. Subsequent plasma-chemical reactions in the spark discharge produce contaminants that are adsorbed onto internal surfaces thereby reducing V_{sb} and causing intermittent prefires and misfires. Proper preventative maintenance of the switches can prolong their useful life. For repetitively pulsed applications, average heating due to mechanism (iii) may also be an important factor, especially if the temperature of the bulk electrode material is allowed to increase well above ambient. Series SG switches are cooled primarily by the internal gas flow and maximum life expectancy will only be obtained using the recommended flow rate. For extreme duty, we offer a finned heat sink (model HEX-101) that bolts directly to the top aluminum plate.

Maintenance. Periodic disassembly and visual inspection are recommended, and severely pitted electrodes may be burnished to restore nominal operating characteristics. For best results, the electrodes and insulator should be cleaned with a solvent that leaves minimal residue, e.g., ethyl or isopropyl alcohol in distilled water. Also clean the O-rings and apply a light coating of high-vacuum silicone grease before assembly. For the smaller-size switches (models SG-101 through SG-141), note the relative orientation of the top and bottom plates prior to disassembly, perform the maintenance operations as discussed previously, and then rotate the top plate by 180° before assembly to promote even electrode wear.

Our large switches (models SG-151 through SG-184) have alignment markers for the top and bottom plates. The bottom plate is stamped with a reference mark on the outer edge (∧), while the upper plate has either three or four numbered marks (∨1, ∨2, ∨3, ∨4). Before disassembly, note the orientation number and then perform the cleaning operations. Assemble the switch using the next number in the orientation schedule, e.g., if the switch is in orientation #2 prior to disassembly, then assemble in orientation #3. This maintenance procedure promotes even erosion of the electrodes. ***IMPORTANT:*** Switch models SG-151 and SG-161 (four-channel trigatrons) must be assembled using the prescribed orientations; failure to observe the alignment marks will result in improper operation, possible damage to the switch, and will void the warranty. The insulator is designed to be self-centering with respect to the upper and lower electrode plates. The assembly screws or bolts must be uniformly tightened and the recommended torque is as follows:

Models SG-101 through SG-141:	15-16 cN-m (28-30 in-oz)
Models SG-151 through SG-184:	1.0-1.2 N-m (180-220 in-oz)

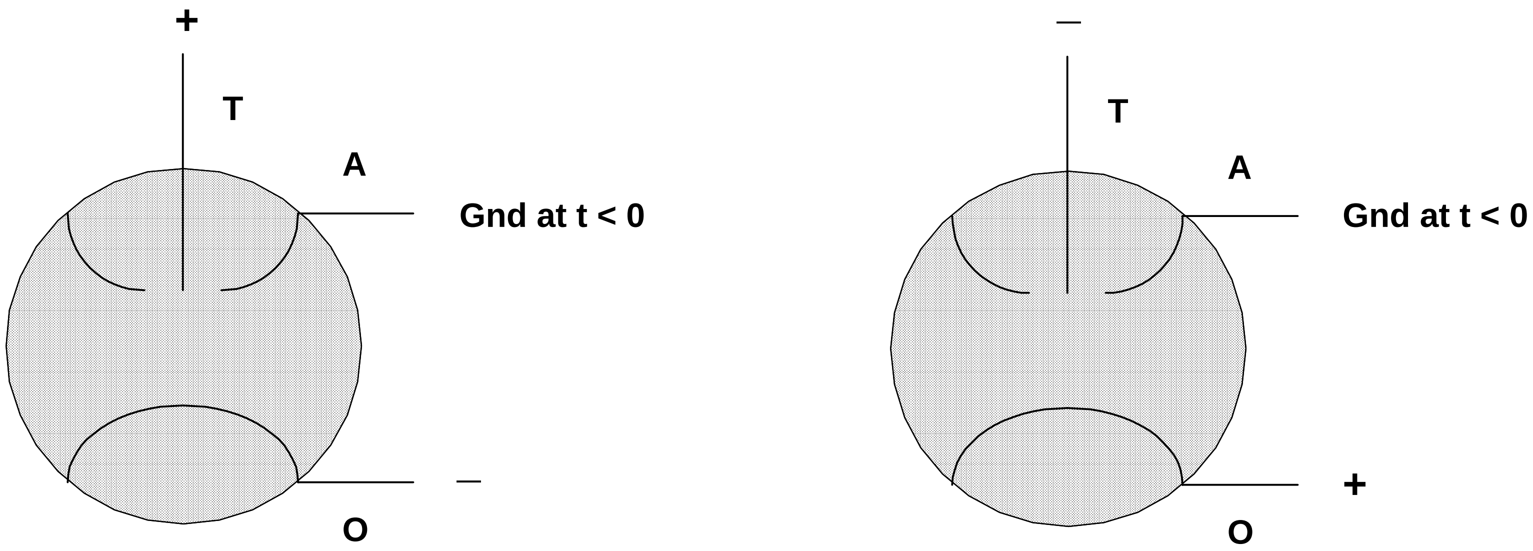
Our switches can be refurbished at the factory for approximately one-third the cost of a new unit. This procedure involves cleaning the switch and replacing both main electrodes and the trigger electrode. Standard-duty switches can also be upgraded for heavy-duty operation by replacing the used electrodes with our -75C series electrodes. Please inquire for further information and a quotation.

Electrical Connections

Trigger Mode. For trigatron switches, the trigger mode is defined by the relative polarities of the trigger (T), adjacent (A) and opposite (O) electrodes. As depicted in Figure 1, there are two heteropolar and two homopolar modes. In general, mode A offers the widest operating range with smallest breakdown time and jitter. Homopolar operation (modes C and D) is strongly discouraged.

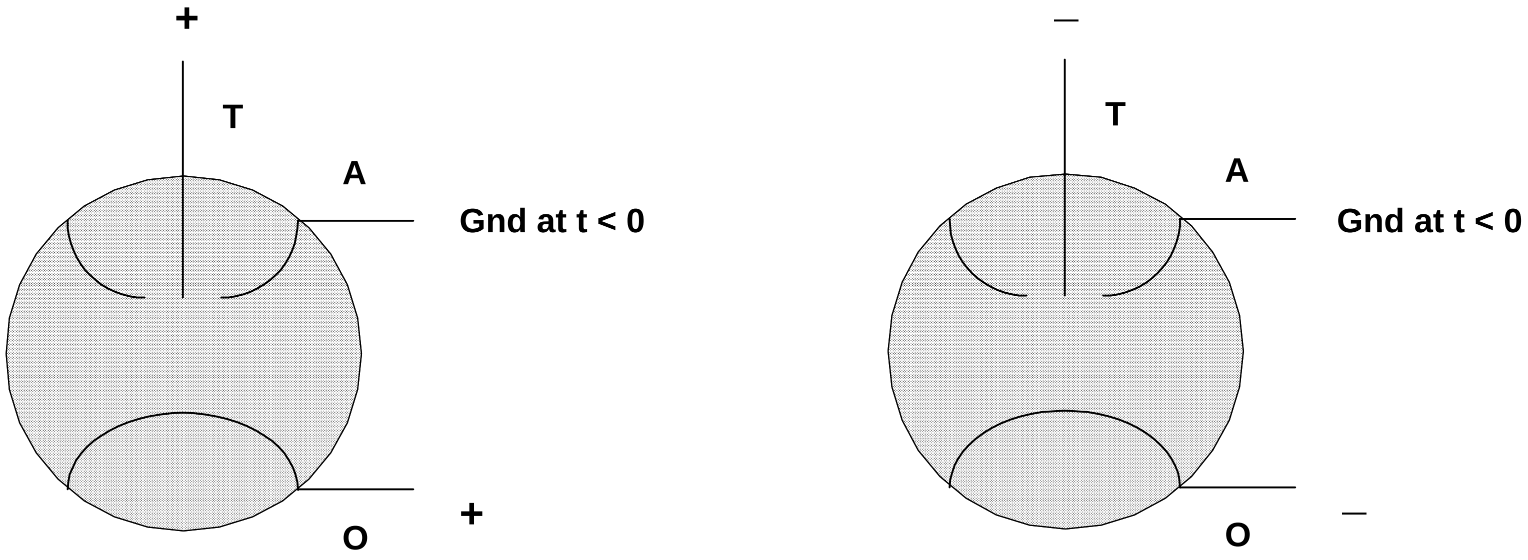
Representative Circuits. Representative circuit diagrams for series-switching and crowbar applications using trigatrons are shown in Figures 2 through 5. All circuits use trigger mode A and the heavy lines denote low-inductance (e.g., strip-line) conductors. Circuits labeled *typical* employ negative-charging power supplies while circuits labeled *alternative* employ positive-charging power supplies. Charging inductors (L_c) and/or resistors (R_c) between the HV power supply and energy-storage capacitor C are not shown and, in fact, these elements may be omitted if a constant-power supply is used. As recommended in the schematic diagrams, the trigger pin should be electrically decoupled using a 500 pF ceramic (*doorknob*) capacitor, especially if the adjacent electrode operates at non-zero potential relative to ground at any time during the charge-discharge cycle. Under no circumstances should a resistor be placed in series with the trigger plug. The trigger transformer (TR) should be placed in close physical proximity to the switch and a crimp-type spark-plug connector is supplied with the switch. The required voltage isolation rating for the trigger transformer will be greater for the *alternative* circuits because the adjacent electrode is floating at high potential. In all examples, the primary current paths are denoted by heavy lines and these conductors should be designed for low self-inductance.

For the series circuits (Figure 2), R_p is a parallel resistor for use with loads that are initially at high impedance (e.g., gas-discharge loads); choose R_p to give 1-5 A of switch current before load conduction. As shown in Figure 2, the load floats at high potential during the charging phase. If it is absolutely necessary that the load remain at zero potential prior to discharge, then the load may be placed between the adjacent electrode and ground as shown by the circuits in Figure 3. These circuits will yield the fastest turn-on, lowest jitter, and maximum repetition rate over the widest range of charging voltage.



Mode A (heteropolar)

Mode B (heteropolar)



Mode C (homopolar)

Mode D (homopolar)

Figure 1. Trigger-mode designations

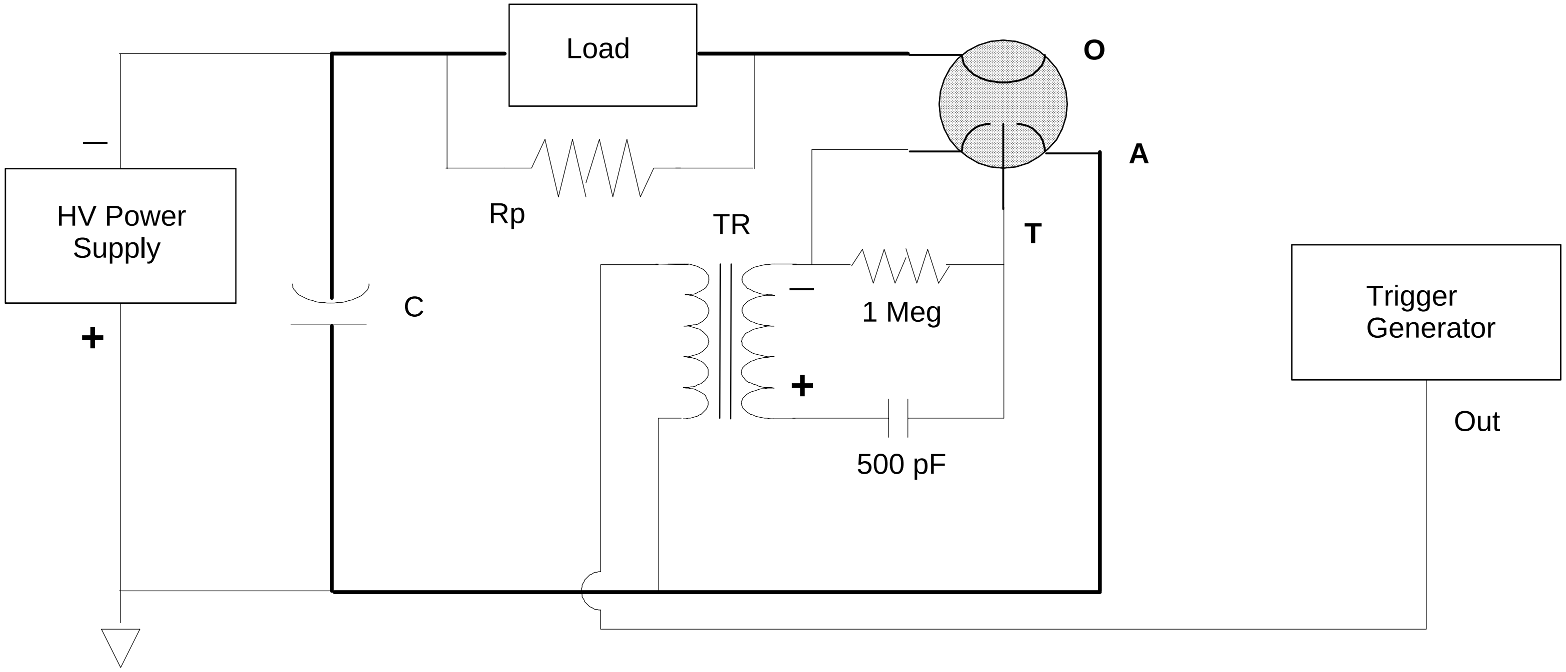


Figure 2(a). Typical Series Circuit

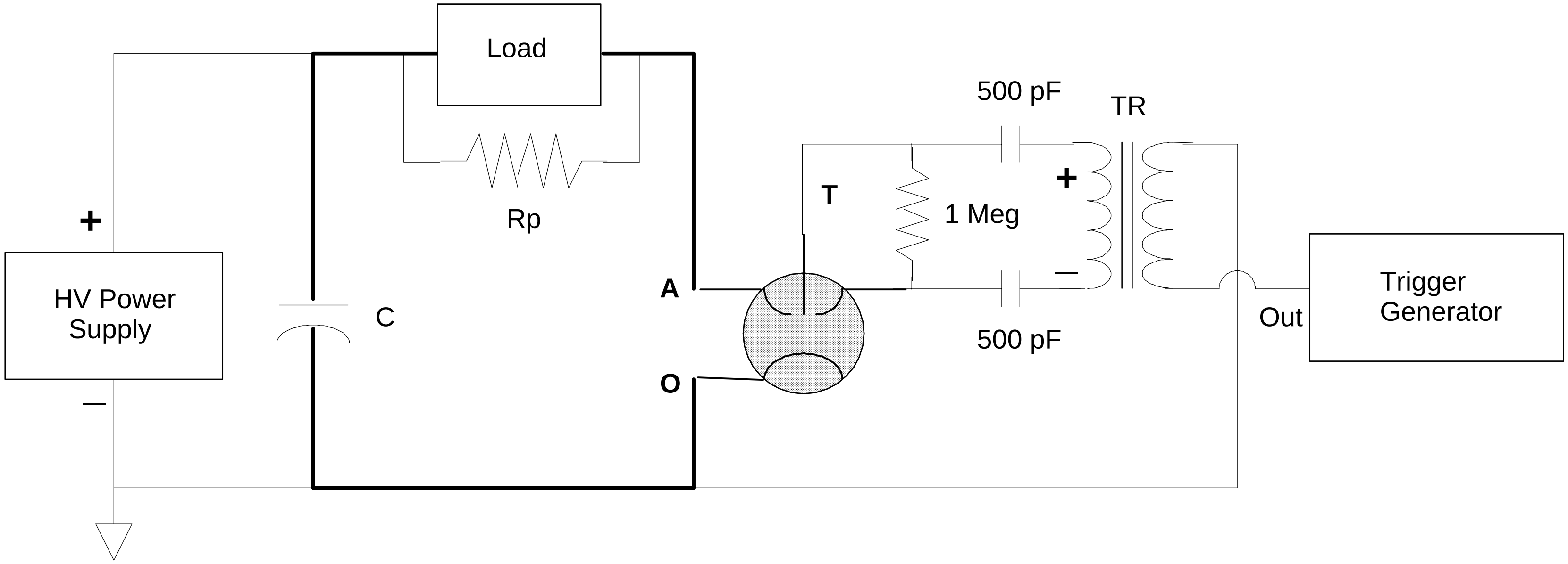


Figure 2(b). Alternative Series Circuit

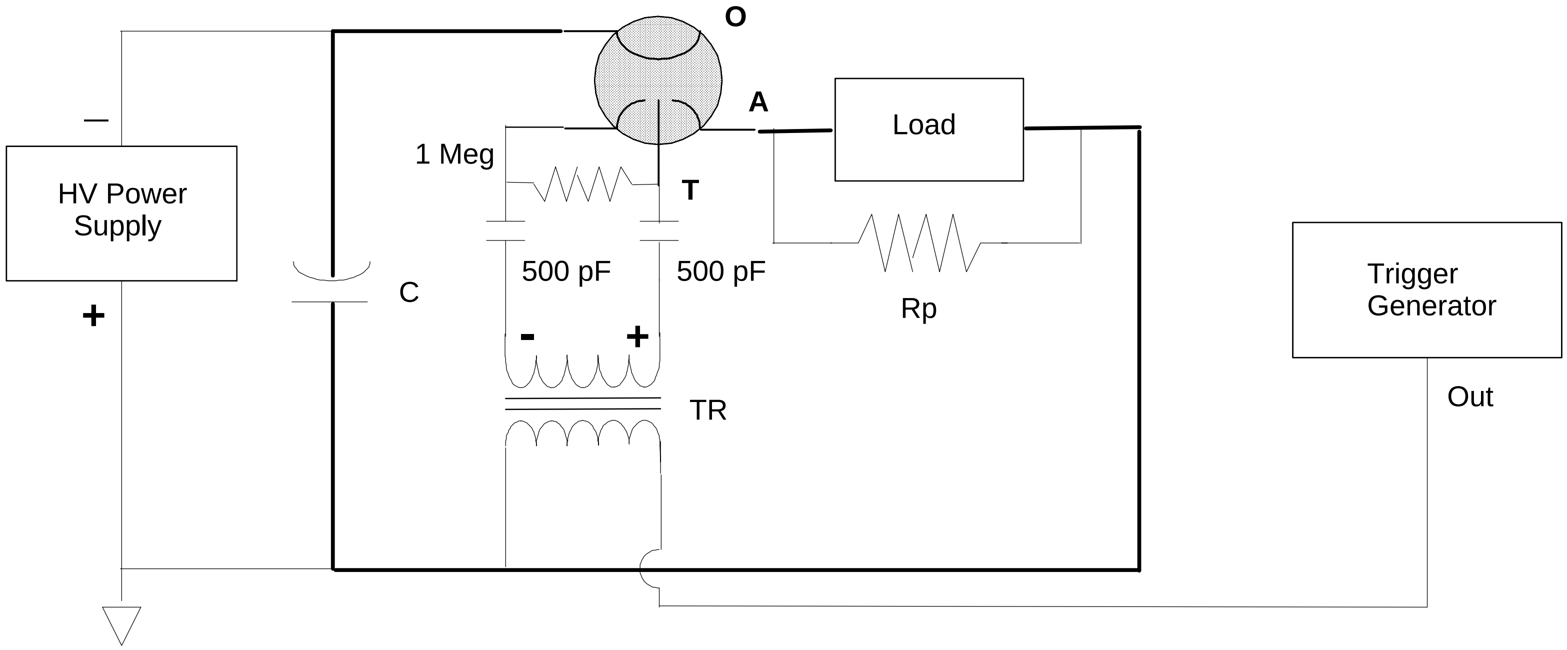


Figure 3(a). Isolated-Load Series Circuit (Negative Charging Voltage)

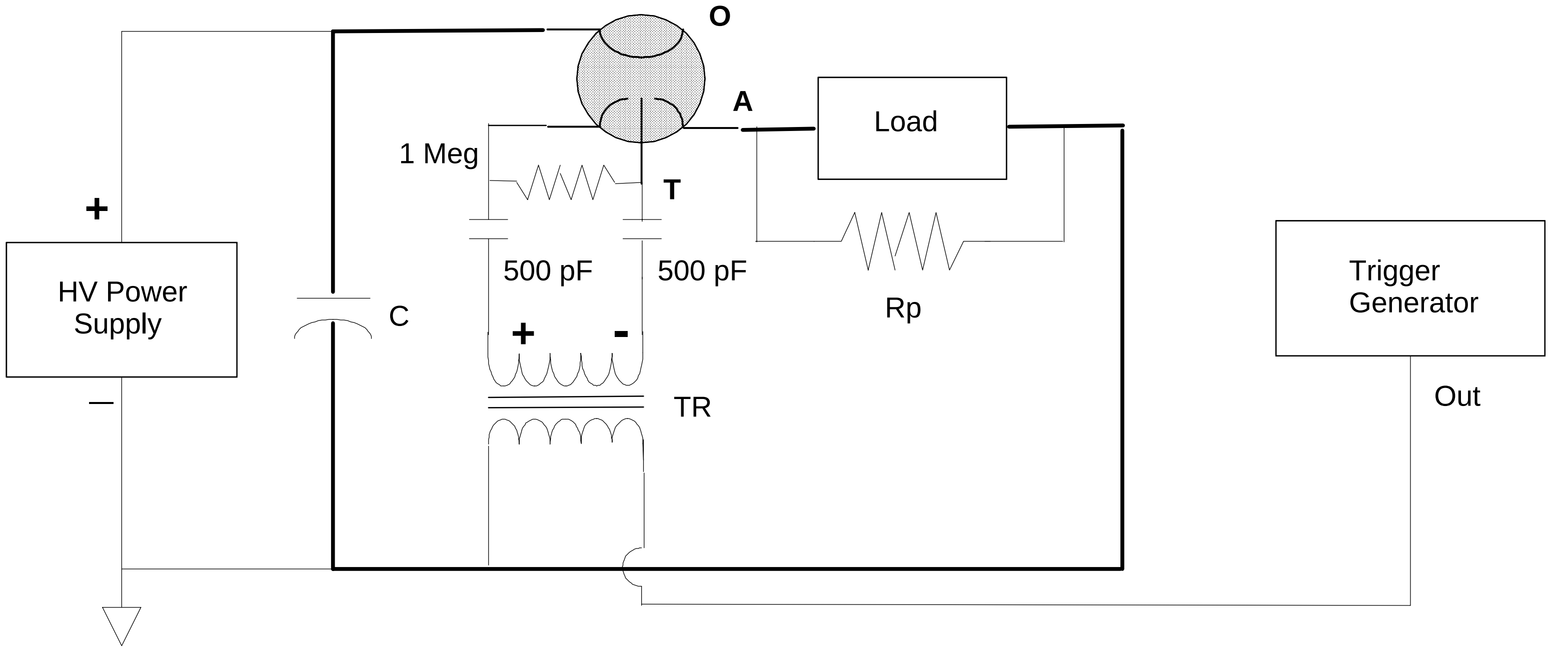


Figure 3(b). Isolated-Load Series Circuit (Positive Charging Voltage)

For the crowbar circuits (Figure 4), the impedance of all circuit elements between the energy-storage capacitor and switch Z_1 must be less than the impedance of all elements between the switch and load Z_2, otherwise closure of the switch will not afford adequate load protection. These impedances include the self-inductances of the conductors (e.g., strip-lines).

Field-distortion switches require triggering arrangements as shown in Figure 5. Two high-voltage resistors of equal value, R_b, ensure that the static potential of the trigger ring is one-half the potential difference across the main gap and decoupling capacitors, C_b, prevent inadvertent damage to the trigger transformer. Again, the trigger transformer (TR) should be placed in close physical proximity to the switch to achieve a fast rise-time trigger pulse. Electrical connection to the trigger ring is by means of 0.25-inch (6.4-mm) brass rod with jack. This rod penetrates the insulator and is sealed using a plastic compression fitting. One lead from the trigger transformer is soldered into a mating plug that supplied with the switch. It is imperative that the polarity shown in this schematic diagram be observed to assure reliable triggering.

Since our switches are designed for use with low-inductance strip lines, templates are included to aid in layout and cutting. For our models SG-101 through SG-141, electrical attachment to the top and bottom electrodes is by means of four #10-32 (M5) screws arranged on a 3.50 inch (8.88 cm) bolt circle for switches with English (-E) or metric (-M) fasteners. Our large switches (models SG-151 through SG-184) have sixteen ¼-20 (M6) bolt holes arranged on an 9.25-inch (23.50-cm) bolt circle. Button or pan screws are supplied for attachment of the conductors. The spark plug (trigatron models) is sealed with an O-ring, so minimal torque is needed.

The circuits shown here are examples only and do not represent all possibilities. For more complex systems, we provide complete engineering assistance on a contract basis.

The entire switch may be immersed in transformer oil or SF_6 gas. We recommend Exxon Corporation UNIVOLT 60 oil for optimum high-voltage service. For $V_{op} \leq 30$ kV, the switch may be operated in the ambient environment depending upon altitude and relative humidity.

Parallel Operation of Switches. Parallel circuits, with two or more switches discharging into a common load, allow larger currents to be commuted while reducing the total circuit inductance. Use of a common trigger transformer is not recommended; each switch should be triggered by a separate fast-rise-time transformer. If each subsystem consists of a capacitor, switch, and trigger transformer, then the individual capacitors must remain electrically isolated during the charging cycle. This is best accomplished using separate charging inductors or resistors, or for repetitively pulsed systems, separate constant-power supplies.

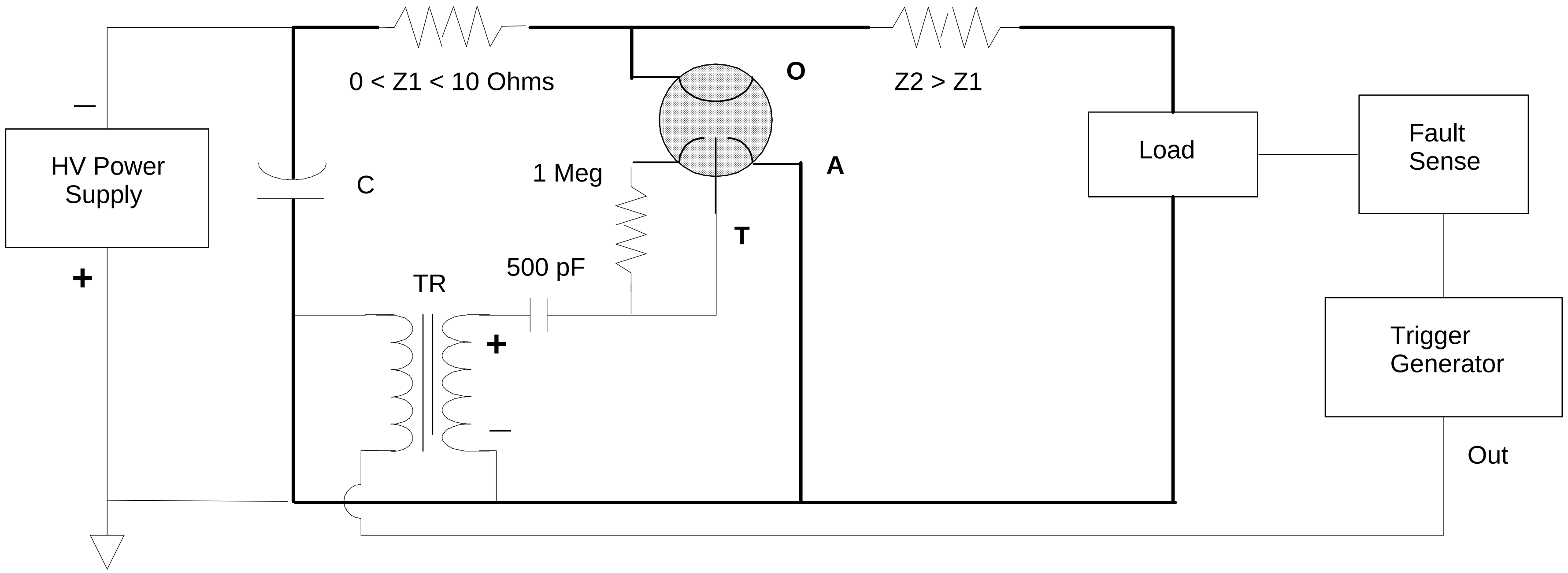


Figure 4(a). Typical Crowbar Circuit

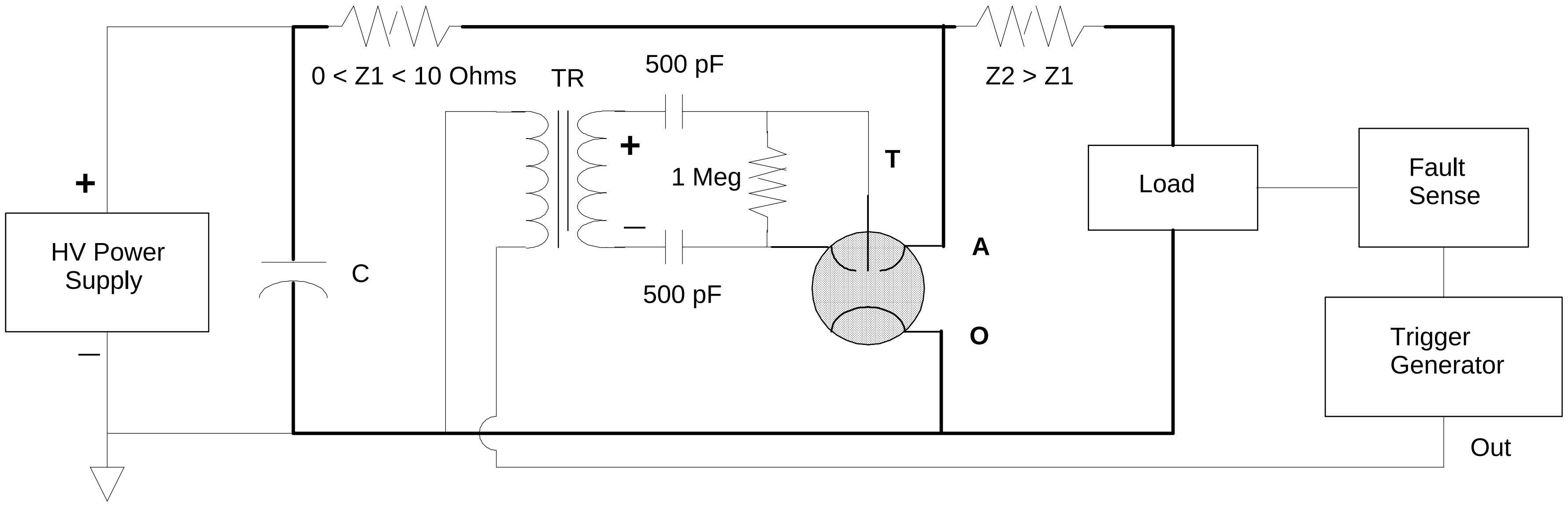


Figure 4(b). Alternative Crowbar Circuit

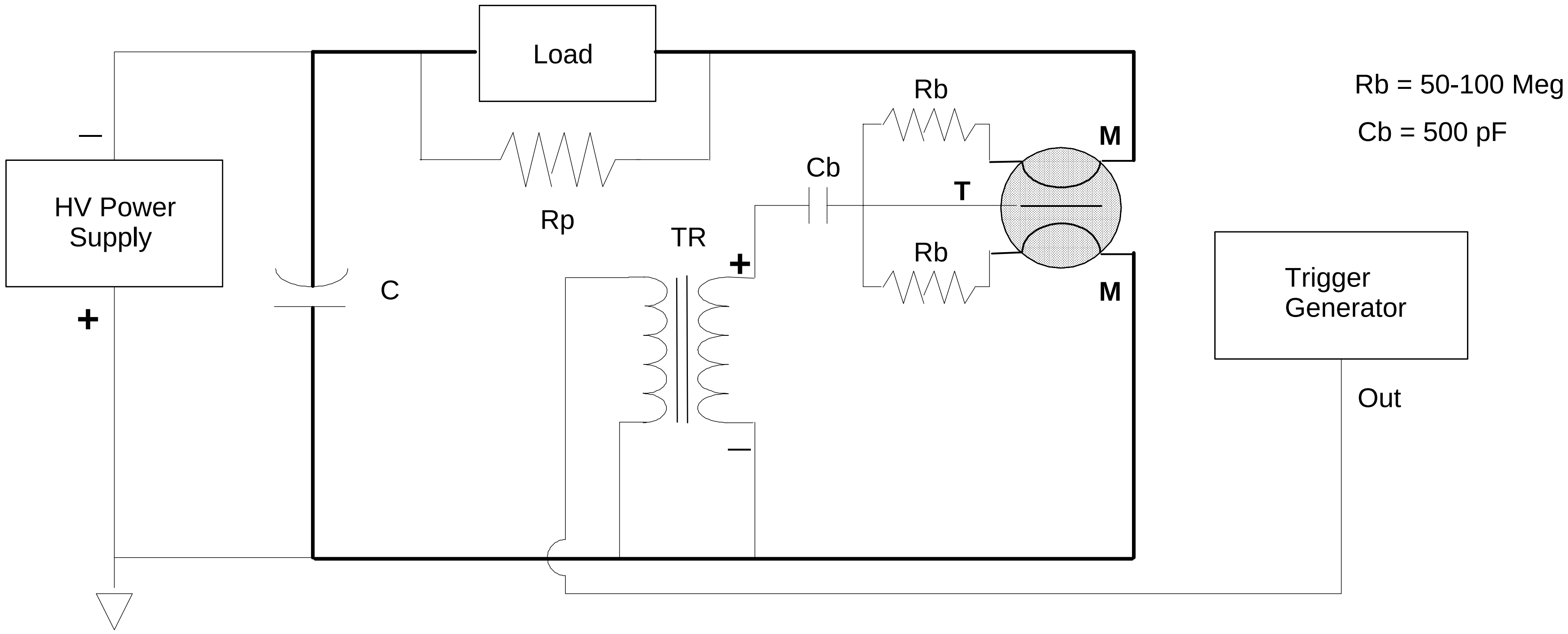


Figure 5(a). Field-Distortion Switch: Typical Series Circuit

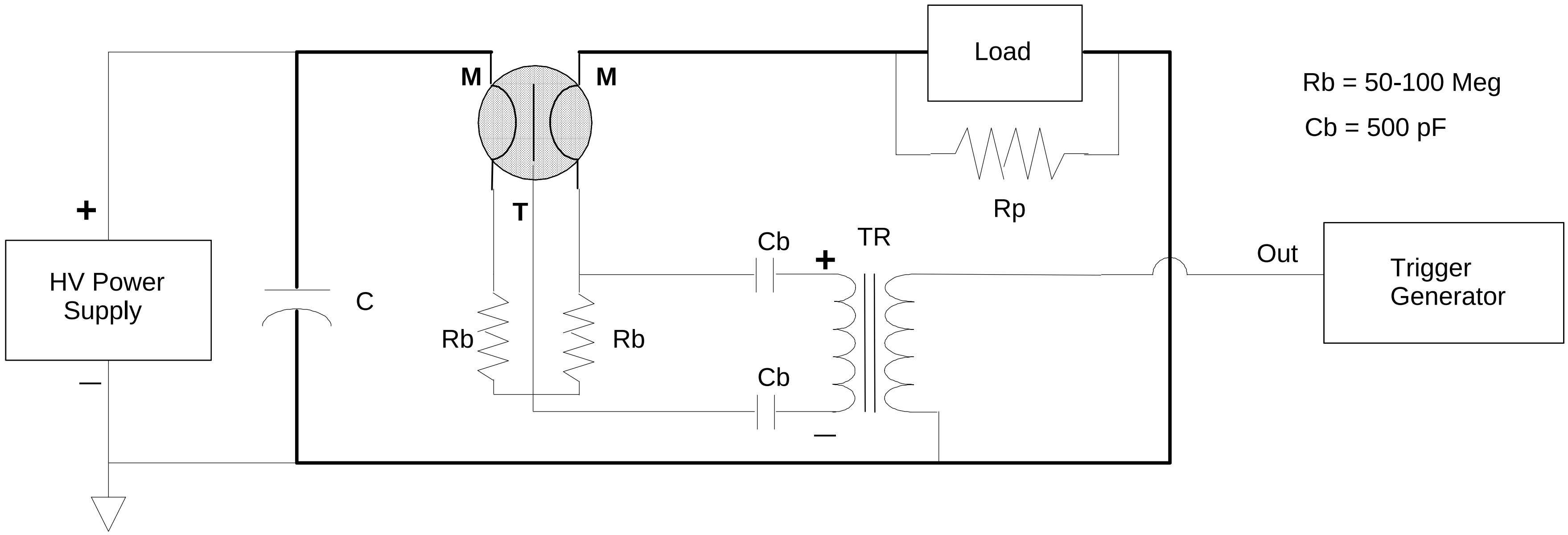


Figure 5(b). Field-Distortion Switch: Alternative Series Circuit

Gas-Supply Requirements

A pressurized gas supply [typically N_2, synthetic air (21% O_2, 79% N_2), or dry air] is required for operation. We recommend a minimum gas purity of 99.995% and the total hydrocarbon plus water vapor content should be <10 ppm. The presence of water vapor and low-ionization potential hydrocarbons can significantly reduce the breakdown potential. Under no circumstances should *welding grade* gases or unpurified, unfiltered compressed air from the ambient environment be used. In addition to degrading the spark-gap hold-off potentials (both static and repetitive), hydrocarbon impurities undergo various plasma chemical reactions in the discharge and are adsorbed onto the insulator, further degrading performance and life expectancy. Under extremely contaminated conditions, surface tracking along the interior surface of the insulator will result in highly erratic operation and serious damage to the switch. Periodic disassembly, inspection, and cleaning of the switch are recommended.

During repetitive closure at **maximum** rated operating conditions, the **minimum** gas flow rate should be

Models SG-101 through SG-141: $$\dot{V}_{gas} = 3.6\, f \text{ (LPM)} = 7.7\, f \text{ (SCFH)}$$

or

Models SG-151 through SG-184: $$\dot{V}_{gas} = 20\, f \text{ (LPM)} = 42\, f \text{ (SCFH)}$$

where *f* is the repetition rate (pulses per second), LPM denotes liters per minute, and SCFH denotes standard cubic feet per hour. These flow rates may be reduced for less stringent discharge conditions. Voltage-pressure curves for the recommended gases and the particular SG model ordered are provided in the **User's Guide**. Use polyethylene or polypropylene tubing (¼" or 5/16" = 8 mm OD) for the supply and outlet gas lines. The ends should be cut squarely and inserted fully into the Parker fittings. These fitting utilize both capture rings and O-rings, hence a good seal is obtained by finger tightening. The gas pressure regulator should be installed on the supply-line side while the internal pressure gauge and flow meter should be installed on the outlet-line side.

Other gases may be utilized for special-purpose operation. For example, argon will allow the switch to operate at much lower voltages, but runaway (self-triggering) will occur for $f \geq 30$–50 pulses per second (pps) unless sulfur hexafluoride (SF_6) is added. A 10% $SF_6 - N_2$ mixture will permit the switch to operate at higher voltages. The highest repetition rate and smallest electrode-erosion rate are obtained with hydrogen, but safety precautions are advised. Please consult us for special applications.

IMPORTANT: For models SG-101 through SG-141, the maximum internal pressure is 30 psig (210 kPa gauge) or 3.0 atm absolute for switches with nylon fasteners and 50 psig (340 kPa gauge) or 4.4 atm absolute for switches with stainless steel fasteners. For our large switches (models SG-151 through SG-184), the maximum internal pressure is 25 psig (170 kPa gauge) or 2.7 atm absolute.

Replacement Parts

User-replaceable parts are available from the manufacturer. The Buna-N O-rings are standard sizes and are widely available. The trigger plugs for the trigatron switches, however, are specially modified for this application. Replacement parts and current prices are as follows:

200-14	O-ring (Trigger Plug)
200-150	O-ring (Main Electrodes SG-100 through -140 series)
200-364	O-ring (Main Electrodes SG-150 through -180 series)
BP5-ESM	Trigger Plug (SG-100 series)
N12-YCM10	Trigger Plug (SG-110, -120, and -140 series)
N12-YCM13	Trigger Plug (SG-130, -150, -160, and –170 series)
SG-120-FDR	Field-Distortion Ring (SG-120 series)
SG-180-FDR	Field-Distortion Ring (SG-180 series)

Warranty

All SG-series switches are covered by a manufacturer's limited warranty for a period of one (1) year after purchase. Any defective unit will be repaired or replaced at our option with no additional charge for materials or labor. This warranty is void if the switch has been modified or subjected to deliberate misuse. For warranty service, simply return the switch freight prepaid to:

R. E. BEVERLY III AND ASSOCIATES
3437 Woodstone Drive
Lewis Center, OH 43035-9386
UNITED STATES OF AMERICA
Telephone (+01) 740-549-3944
FAX (+01) 740-549-3954
e-mail sales@reb3.com
URL http://www.reb3.com

Please obtain a return authorization and provide an explanation of the problem. The unit will be repaired or exchanged and returned within one week after receipt. The switch can be refurbished at the factory after the warranty period for a nominal charge. The switch is cleaned, both main electrodes are replaced, and a new trigger plug or field-distortion ring is installed. Please call for a quotation.

The manufacturer's sole obligation under this warranty shall be repair or replacement of a defective switch. Since these switches are to be incorporated into a pulsed-power system of the customer's own design, we bear no responsibility for the proper engineering of these systems or for their safe operation. Under no conditions will the manufacturer be liable for incidental or consequential damages arising from use of this product.

Other Products and Services

Please inquire about other products and services:

Low-inductance, high-voltage, aqueous-electrolyte resistors
Surface-discharge light sources
Surface-discharge switches
Complete pulsed-power systems
Laboratory data acquisition software
Gas-discharge laser development
Specialized diagnostics for plasma-physics research

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