Design Considerations for Triggering of Flashlamps

by Alex D. McLeod

Introduction

Xenon flashlamps (bulbs or tubes) are devices that emit large amounts of spectral energy in short duration pulses. Power supply energy accumulates in a storage capacitor. When this energy is released and dissipated it forms a highly excited xenon plasma within the flashlamp. The energy released covers a wide spectral range from ultraviolet (UV) to infrared (IR), closely resembling sunlight.

This intense pulse of radiant energy is used in many applications including applications which; stop motion, pump lasers, provide a stable spectral source for absorption or fluorescence measurements, cure polymers with UV, strip paint, or simply provide a visible beacon.

Theory of Operation

The charged energy-storage-capacitor is normally connected across the two main electrodes (commonly called ANODE and CATHODE) of the flashlamp. The voltage to which this capacitor is charged is usually lower than that which would cause the xenon to ionize. The process which effects the initial ionization is known as TRIGGERING. Triggering creates a voltage gradient (Volts/Inch) in the gas of sufficient magnitude to cause ionization.

Figure 1 shows typical flashlamp triggering characteristics. It should be noted that the curves are somewhat dependent on the triggering method and other factors external to the flashlamp itself. For instance, the arrows on the curve limiting the reliable flash area indicate how the curve typically migrates back and forth over the life of the flashlamp.

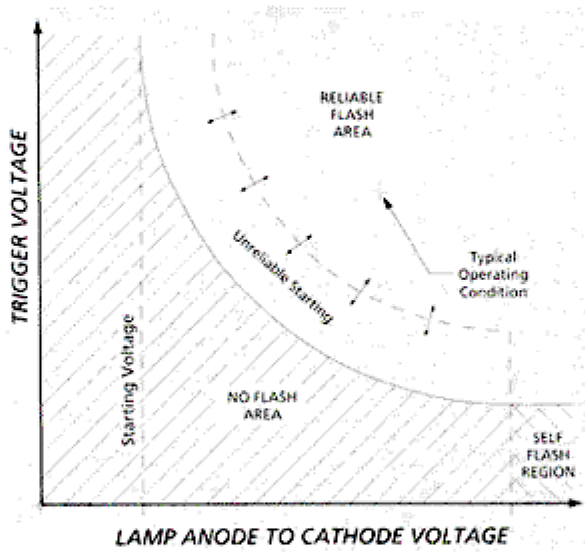


Figure 1. Typical Flashlamp Triggering Conditions

Most triggering schemes use a trigger transformer to produce high voltage pulses of short duration. Several different circuits have been developed which introduce this voltage to achieve ionization. Once this has occurred as evidenced by a thin streamer between the main electrodes, a conductive path exists through which the energy-storage-capacitor can discharge. As the level of ionization increases, the streamer increases in cross section and produces an intense flash.

Methods of Triggering

Most of the triggering schemes can be grouped into three categories;

1. External
2. Series Injection
3. Pseudo-Series Injection

Two other commonly used circuits which are initiated using one of the above three triggering methods are;

4. Simmer Mode
5. Pseudo-Simmer Mode

Another variation on these circuits which indirectly uses a trigger transformer is;

6. Overvoltage Triggering

1. External Triggering

External triggering uses a high voltage trigger pulse to create a thin ionized streamer between the anode and cathode within the lamp. Ionization starts when gas adjacent to the tube wall is excited by the voltage gradient induced by this high voltage pulse from the trigger transformer. The coupling of this voltage to the lamp can be accomplished in any one of several ways. (See Figures 2A - 2E)

A thin nickel wire can be wrapped around the surface of the glass (or quartz) envelope (tube) as shown in Figure 2A. The wire must touch the glass over as much as possible of the length of the envelope, between the electrode inner tips, for the most reliable operation, although even a minimum of contact can be satisfactory if a higher peak trigger voltage is applied. The trigger transformer high voltage output (secondary winding) is connected to one end of this wire.

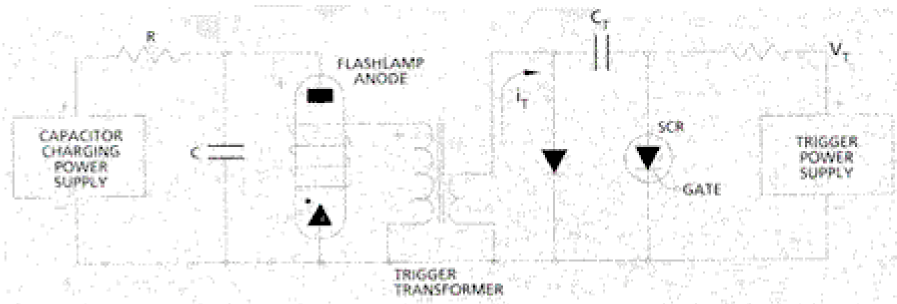


Figure 2A. External Triggering Schematic

The trigger voltage required to reliably trigger a particular flashlamp depends on the arc length, bore diameter, fill pressure, electrode material and is normally given in the flashlamp characteristic data. Other factors such as ambient radiant energy and aging characteristics of the lamp also affect triggering requirements.

The trigger pulse width is important using this method because a finite amount of time is required for the ionized streamer to propagate down the bore of the flashlamp. Triggering has been found to be most reliable when the pulse width is at least 200 nanoseconds per inch of arc length.

If a wrapped trigger wire is for some reason inconvenient, then the trigger pulse may be applied to a conductive bar (see Figure 2B) or a conductive reflector (see Figure 2C). In these cases the conductive component should be as close to the lamp as possible and no more than 1/4 away, and a somewhat higher trigger voltage should be employed.

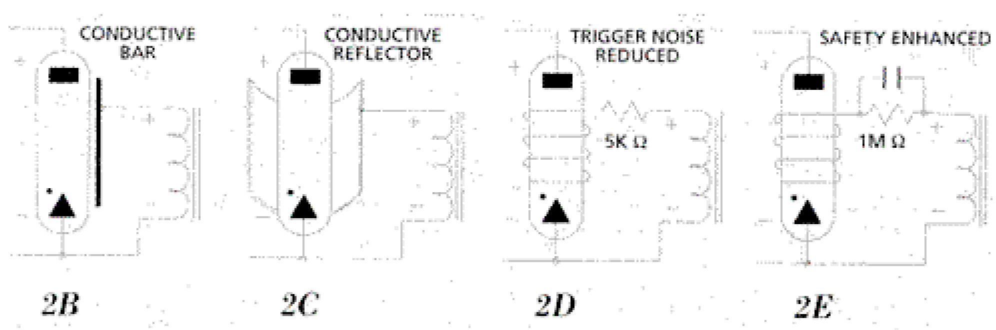


Figure 2B thru 2E. External Triggering Methods

Since the trigger transformer has to supply a high voltage pulse but very little current (only about 100 to 300 μA), it can be made small and lightweight. The turns ratio is usually high to accommodate lower voltage components in the primary circuit. The trigger pulse is produced by discharging a capacitor into the primary winding of the trigger transformer using either a mechanical switch or a semiconductor device such as an SCR or a gas filled switch such as a triggered spark gap. Care must be taken in the selection of the switch to be used to ensure that the rate of rise of current can be accommodated without device failures. This is especially critical when an SCR is used. Also, camera shutter switches which are sometimes used to trigger a flash often have fragile, sensitive contacts and an intermediary switch is usually required to prevent the trigger transformer primary current from causing contact damage.

Generally speaking, the polarities of the anode-to-cathode voltage should be arranged so that the voltage stress or gradient (Volts/Inch) is maximized in the vicinity of the anode (or cathode) of the flashlamp. Voltage from the energy-storage-capacitor should always be arranged so that the anode is more positive than the cathode. Since any node in the circuit can be chosen to be grounded, this leads to a variety of possible circuits. Some possibilities can be eliminated by ensuring that the trigger transformer secondary windings start-to-primary insulation is not stressed any greater than as specified in the data. Careful examination of the potentials in the circuit will show the best circuit for the application.

EMI and Noise

Flashlamp triggering using fast rising, high voltage pulses is an inherently noisy (EMI) procedure. The trigger current, upon ionization of the gas (xenon), contains discontinuities and irregular pulse-to-pulse anomalies. The harmonics generated can be measured into the gigahertz region, with various peaks being exaggerated by wire lengths and ground planes.

Relief can usually be obtained by good shielding, enclosure design and ground layout. The noise from the trigger discharge can also be lessened by including a resistor in series with the high voltage secondary lead (see Figure 2D). This slows down the discharge of the parasitic secondary winding capacitance. A 2 Watt carbon composition resistor of about 1 to 5 K Ohms is usually effective. Metal-film resistors with helical paths usually fail due to delays of voltage wavefronts and subsequent turn-to-turn breakdown at the transformer end of the resistor and are therefore not recommended.

Safety is another consideration that may lead to the selection of one circuit over another. For instance, one should consider the consequences of arcing between the high-potential end of the energy-storage-capacitor. If this occurred, the capacitor would discharge into the winding and perhaps destroy it. One possible solution would be to include a capacitor/resistor network in the discharge path (see Figure 2E) which would pass the trigger pulse without attenuation but prevent the discharge of the energy-storage-capacitor into the winding. About 500 picofarads in parallel with 1 megohm would suffice in most cases, the capacitor being a disc-ceramic type able to withstand about 6 kV.

2. Series Injection Triggering

Series injection triggering passes the discharge current from the energy-storage-capacitor through the secondary winding of the trigger transformer. The secondary winding of the trigger transformer must therefore be designed to carry the total current of the discharge within the ambient temperature design limits. This type of trigger transformer is consequently larger, heavier and more expensive than the external type. There are, however, certain important advantages.

The inductance of the secondary winding (of the trigger transformer) is now part of the discharge circuit and may be utilized to control the energy-storage-capacitor's current pulse waveshape. Since flashlamp life is inversely proportional to peak current, it is desirable to optimize this inductance for damping and design a critically damped circuit. This will produce minimum peak current and prevent current reversal which may damage the flashlamp. The life of the flashlamp is now maximized for the particular energy required and the power requirement now dictates the size of the trigger transformer.

Skin Effect

A certain amount of energy will be dissipated in the resistance of the secondary winding which will be dependent on the arc-resistance of the flashlamp (a non-linear function). Since current risetimes could be in the order of microseconds, skin effect should be taken into account.

In the design of some transformers an attempt has been made to reduce skin effect by winding them with copper strip or doubled wires. It is difficult to predict with precision the exact circuit performance since typically only the DC resistance of the secondary windings are provided in transformer data. If more data is required, it becomes necessary to take measurements using the intended circuit configuration.

The trigger transformer peak secondary output voltage is applied across the anode/cathode of the flashlamp, and is usually somewhat lower than that required for external triggering. Also, the anode to cathode starting voltage is usually much lower. Triggering will be enhanced by any ground planes brought into close proximity of the flashlamp envelope. If desired, a trigger wire (as used with external triggering) may be wrapped around the envelope and brought to ground. A sharp grounded point close to the triggered electrode also enhances triggering by increasing the electric field gradient in that area.

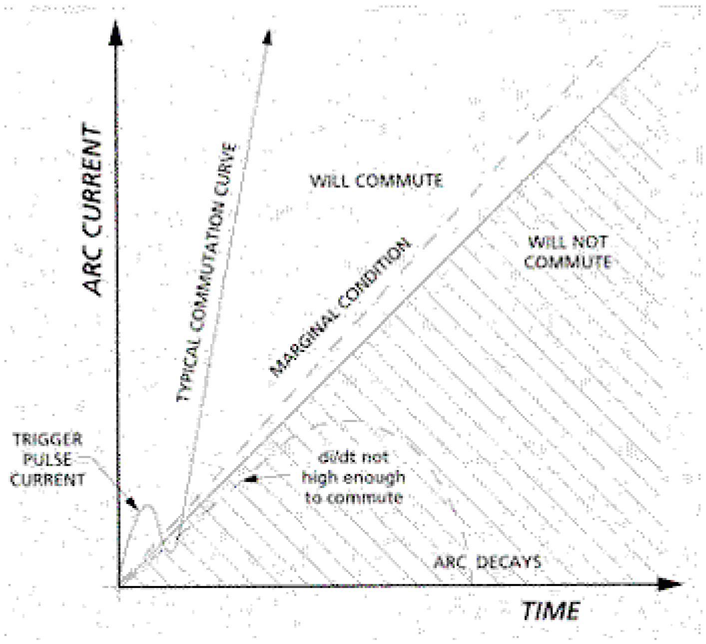
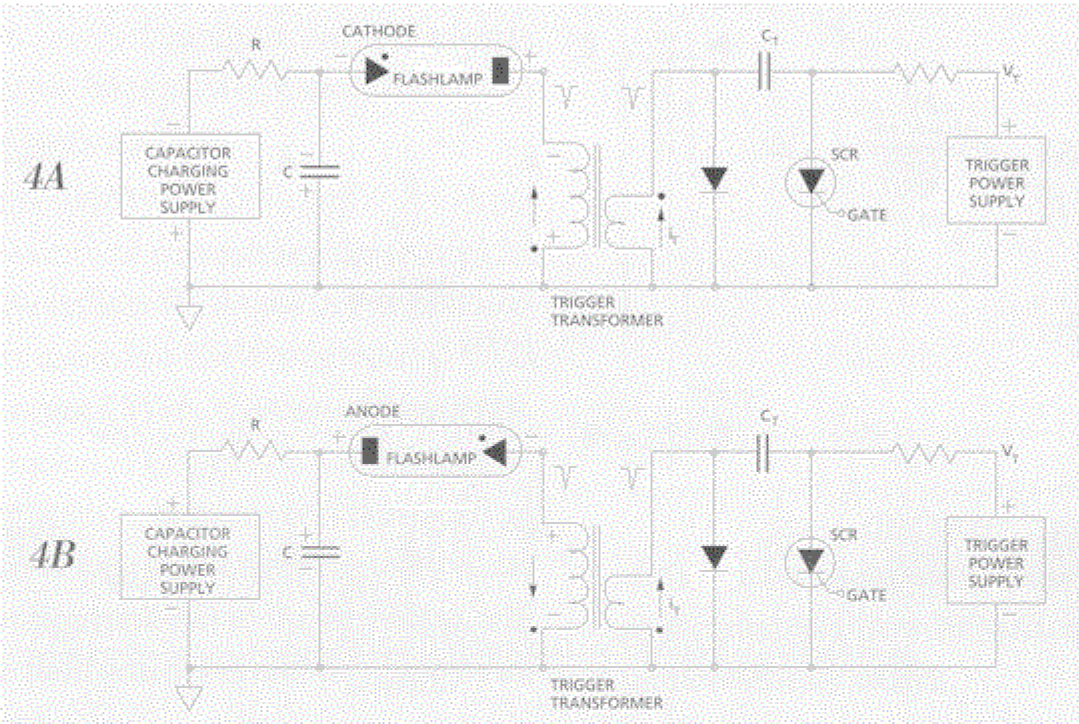


Figure 3. Typical Idealized Arc Commutation Characteristics

Previously, the inductance of the secondary winding was mentioned as being useful in shaping the discharge current pulse. The inductance referred to is the saturated inductance (L_{SAT}) as given in the transformer data tables. Series ignition trigger transformers are usually wound on magnetic cores, either ferrite or silicon steel. This is necessary in order to keep the primary conditions within reasonable limits. The presence of this core may cause problems when considering the rate of change of current (di/dt) in the secondary winding of the trigger transformer. (See Figure 3) The problem is that when unsaturated, this core may inhibit the discharge pulse current rise so much that the lamp won't flash.

Figure 3 illustrates the current/time commutation characteristics of flashlamps. The low excitation inductance of the secondary winding will be considerably greater (say - 50 times more) than the inductance after the core has saturated and the volt-second product of the core must be taken into account. The commutation characteristics of a particular flashlamp, the series injection trigger transformer, and the energy discharge circuit constants may combine to produce a condition where the trigger ionization streamer is quite evident but no energy discharge occurs. Since the interdependence of all of these parameters (some of which are unknown) determine triggerability, it is usually necessary to conduct experiments to ensure reliable operation.

As with external triggering, safety is enhanced using circuit configurations where one end of the trigger transformer secondary is at ground potential. Figure 4 shows the four possible circuit configurations for series injection triggering. Note that the dots adjacent to the trigger transformer indicate the starts of windings. The dot may also indicate the finish of windings should some specific reason exist such as restraints due to insulation. The arrows indicate current flow from positive to negative voltage (i.e. conventional current flow). The arrow at the primary indicates current flow due to the primary trigger discharge and the arrow at the secondary indicates the current flow due to the main discharge. Note that in all of the circuits shown, both arrows point opposite with respect to the polarity dot on the primary to the secondary indicating the remanence after a flash is in the opposite quadrant of the core B-H curve to that in which core saturation occurred. This suggests that, if triggering starts when on the first pulse zero remanance exist in the core, the second and subsequent trigger pulses will be higher due to the greater total change in flux. This should be taken into account when considering triggering reliability margins.



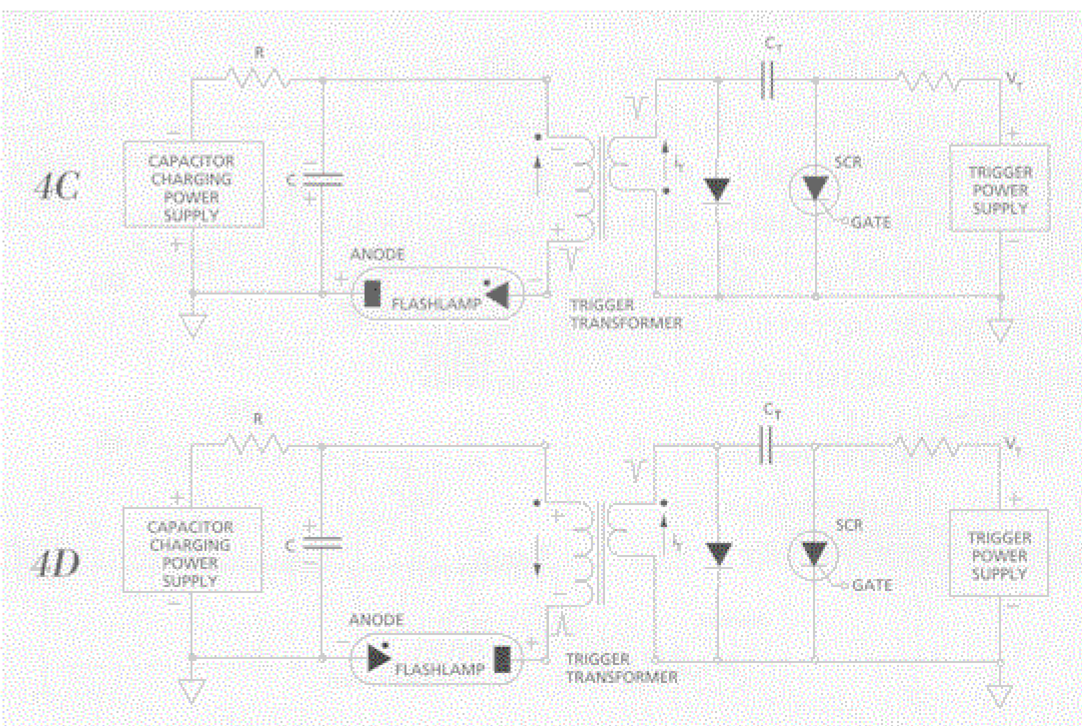
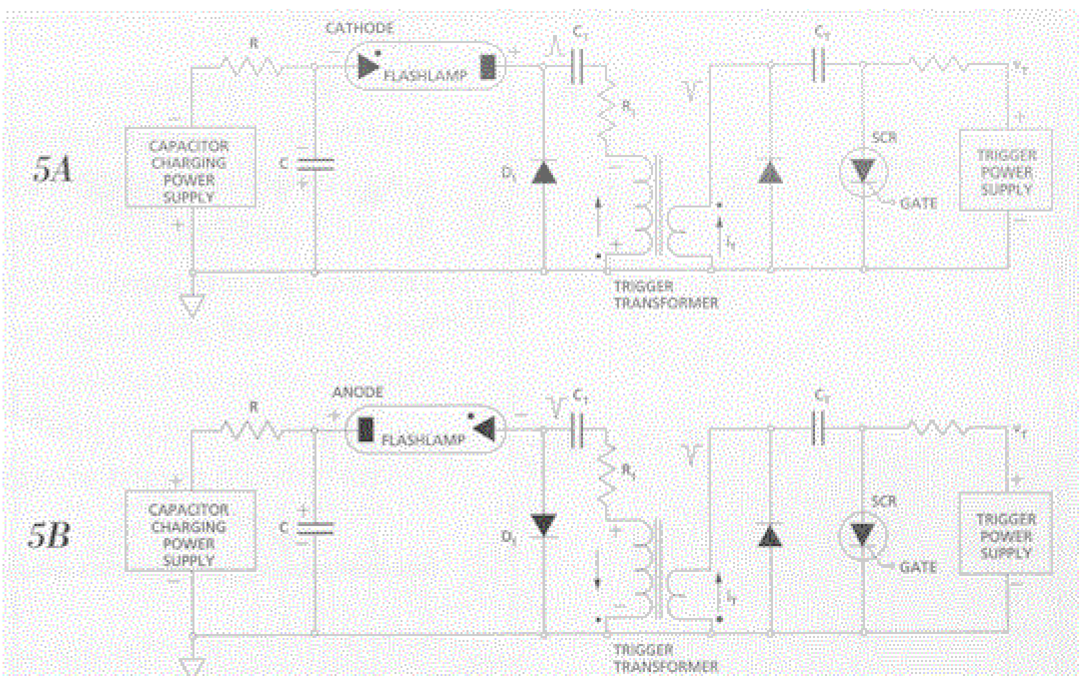


Figure 4. Series Injection Triggering

Furthermore, there are other possible circuit configurations where both arrows may point in the same direction with respect to the polarity dots. In these cases the opposite is true and the pulses after the first pulse will be lower in peak amplitude.

3. Pseudo Series Injection Triggering

Pseudo series injection triggering retains some of the advantages of series injection triggering without some of the penalties, especially those of size, weight and cost. Figure 5 shows four versions of this circuit in various possible configurations of polarities and grounded nodes. The trigger voltage is applied to the flashlamp in the same manner as with series injection, however, in this case the main energy discharge does not flow through the trigger transformer secondary winding. Instead, a path is provided through D1.



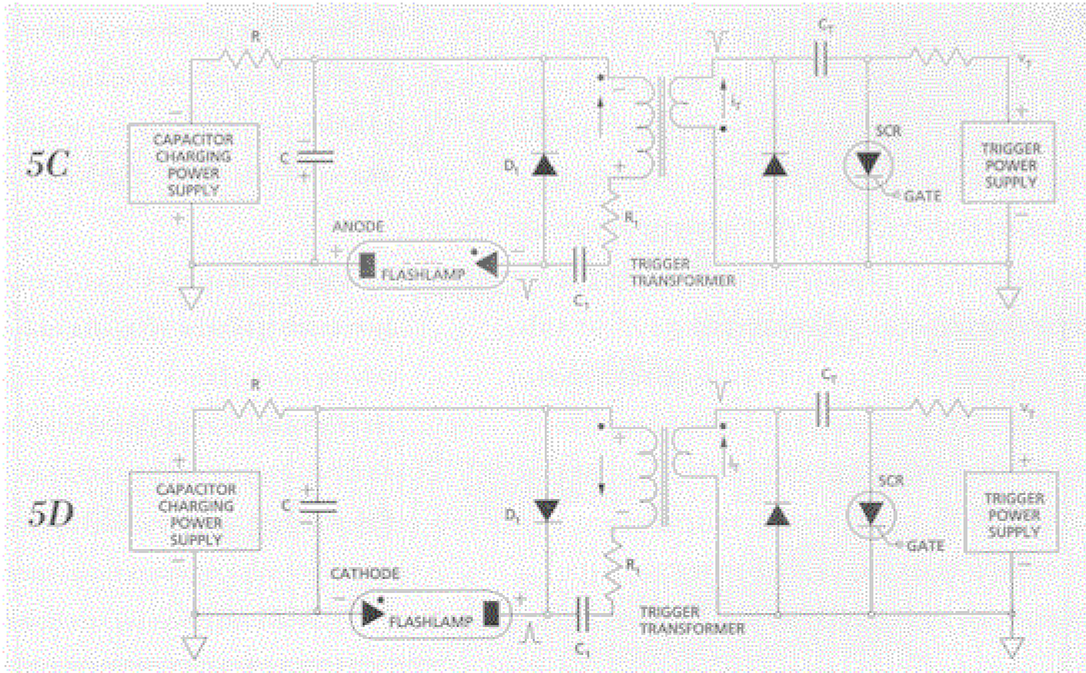


Figure 5. Pseudo-Series Injection Triggering

D1 is constructed of several diode junctions in series and is chosen to be able to carry the main discharge current. It could therefore be a substantial diode depending on the current requirement. The trigger voltage is applied to this diode assembly in it's reverse direction, so that the peak voltage applied across the flashlamp is limited by the reverse breakdown voltage of the diode string. Individual diodes with nominal reverse breakdown voltage of 1000 volts are normally used. This means that the basic silicon material is of high resistivity (100 ohm/cm or higher). Significant loss of discharge energy can therefore be expected. Careful choice of junction profile limits this loss.
Diode assemblies are available from PerkinElmer with these characteristics and reverse breakdown of 10 kV minimum. The resistor R1 shown in the schematics (Figure 5) is useful in the reduction of EMI and is about 5 k ohm, 2 Watt, Carbon composition. The capacitor is included for safety reasons as in other triggering schemes. Judicious placement of grounded features close to the lamp envelope, especially near the triggered end of the flashlamp, will enhance voltage field gradients and produce more reliable triggering.

4. Simmer Mode

The simmer mode technique requires that the flashlamp be triggered only once in a sequence of flashes. A separate power supply with a specially designed load characteristic is used to force the current to continue flowing in the lamp in a low, but stable state of ionization (see Figure 6).

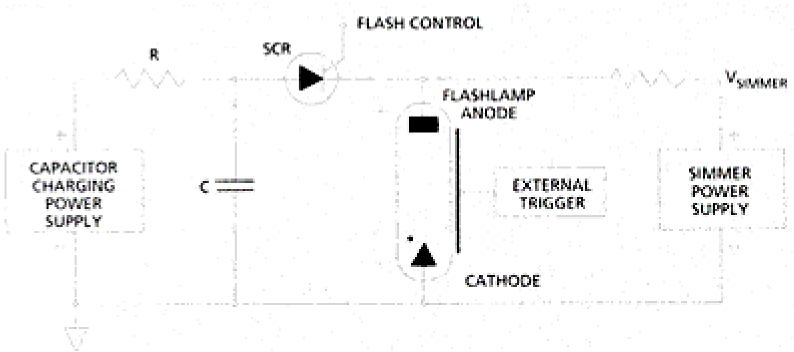


Figure 6. Simmer Mode Circuit

Depending on the flashlamp type, typical simmer current may be from 100 milliamps up to several amperes. The voltage across the lamp will be 100 to 150 volts (see Figure 7). The main discharge energy, obtained from a capacitor charged to a separate power supply, may now be switched into the lamp. A semiconductor switch, such as an SCR (shown) or a gas or vacuum gap may also be used. The gas in the lamp will become more highly ionized, producing a flash as the energy is dissipated. The gas will then be forced to return to the simmer state. Care must be taken in circuit design and layout, that transients due to parasitic elements do not cause deionaization to occur, or that semiconductors or insulation do not become over stressed.

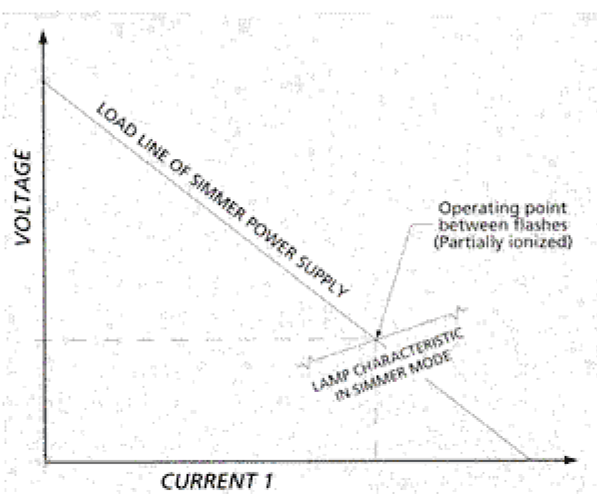


Figure 7. Simmer Power Supply Operation

5. Pseudo Simmer Mode

Pseudo simmer mode is a variation on the simmer mode circuit which combines the simmer power supply with the capacitor charging supply (see Figure 8). Operating conditions are limited by lamp and power supply load line considerations.

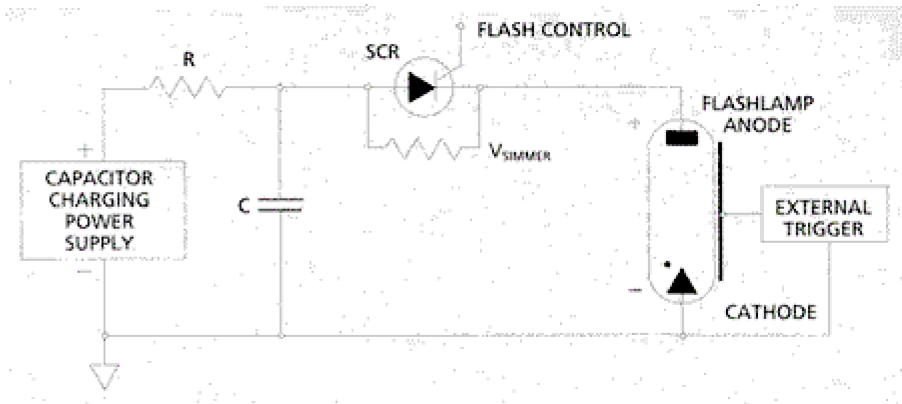


Figure 8. Pseudo-Simmer Mode Circuit

6. Overvoltage Triggering

Overvoltage triggering is a method of flashing a flashlamp without using a trigger transformer and is mentioned here only for completeness (see Figure 9). The energy storage capacitor is charged to a voltage which exceeds the self-breakdown voltage of the flashlamp (typically 10 to 20 kV). The energy is switched into the flashlamp using a high voltage/high current switch. This is typically a triggered spark gap or thyratron. When the switch is activated the flashlamp gas breaks down and a flash is produced.

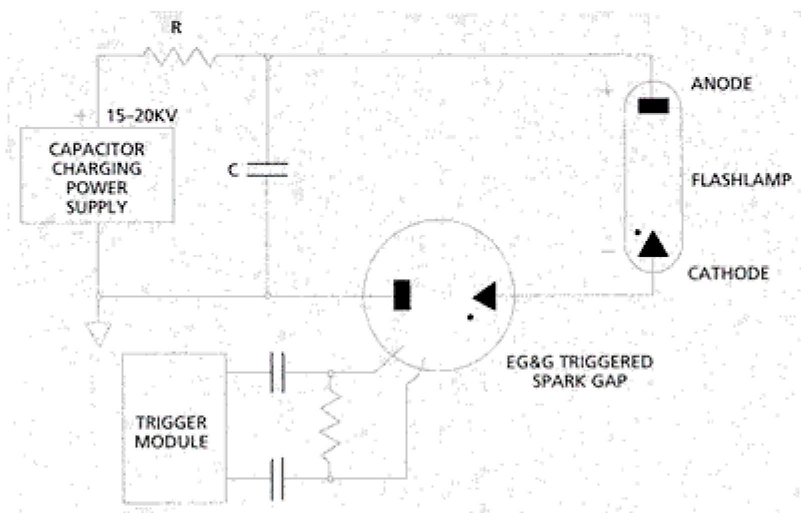


Figure 9. Overvoltage Triggering