SIEMENS

Xenon Flash Tubes Application Notes

Contents

1. Introduction

The Heimann flash tube is a gas discharge device designed to produce pulses of short duration but of high intensity.

The peak intensities achievable with flash tubes are much higher than are obtainable with continuous wave (CW) sources.

The gas normally employed in Heimann flash tubes is Xenon because this gas gives the most efficient conversion of electrical energy into light (photon energy) in the visible spectrum.

Basically the construction of a flash tube is quite simple. A glass or quartz tube is formed to the required shape and is provided with electrodes at each end. The tube is then filled with Xenon gas at an appropriate pressure for the application.

Next there will be a means of triggering the tube, such as for example, a wire wrapped around the outside of the tube, a conducting strip of metallising or transparent conducting coating.

The performance of such a tube will depend upon such things as:–

1. Type of glass or quartz used for the envelope.
2. The arc length and tube bore.
3. The design of the end electrodes and the materials used.
4. The Xenon gas pressure and impurities deliberate or unavoidable.
5. Method of triggering the Flash Tube.

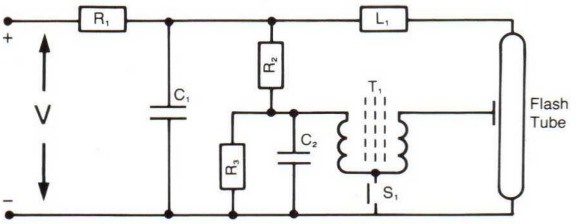
2. Flash Tube Circuitry

What may be considered as a basic circuit is given in figure 1.

In this circuit condenser C_1 is the energy storage condenser which provides the flash energy to the flash tube when it is triggered.

The flash tube is triggered by means of a high voltage pulse from the secondary of the transformer T_1 (in the range 5kV to 14kV depending upon application).

Figure 1 Basic Flash Circuit



V = DC supply voltage
R_1 = Limiting resistance
C_1 = Energy storage capacitor
R_2 & R_3 = Resistors used for dividing voltage
T_1 = Trigger transformer
L_1 = Choke (only required when metallised paper capacitors used)
C_2 = Trigger energy storage capacitor
S_1 = Switch

This pulse applied to the trigger wire (or other arrangement) around the tube causes the gas inside the tube to become ionised which produces a large reduction in impedance between the end electrodes which then remains roughly constant until the discharge is completed.

This current flow through the flash tube excites some of the electrons in the Xenon gas molecules to a higher energy state or in many cases removes the electrons completely from the molecules (ionises them).

It is the return of these electrons to their ground state which releases energy (photons) in the form of light.

The pulse into the primary of the trigger transformer T_1 is produces by closing switch S_1 which causes condenser C_2 to discharge through the primary winding.

The correct voltage is derived for C_2 by charging it from a divider consisting of R_2 and R_3 across the main energy storage capacitor C_1 .

The resistor R_1 is normally required to limit the initial rate of charge into C_1 to avoid damage to C_1 and to limit the current from the voltage source which will flow through the flash tube and if too high would prevent it from extinguishing thereby preventing the condenser C_1 from recharge for another flash cycle.

The series resistance is normally chosen so that the storage capacitor C_1 has time to reach nearly full voltage before the Flash Tube is fired.

As an approximation RC should be about $^{1}/_{5}$ of the required charging time in seconds where R is in ohms and C is in farads. Note R in the calculation will include any source impedance in the supply, for example an inverter transformer.

Charging time in the case of photo flash guns is often in the order of 10 seconds for amateur applications with shorter times for professional units.

In the case of stroboscope applications in order to reduce the mean tube watts at the fastest speeds the value of R, is sometimes deliberately chosen to be higher than normal.

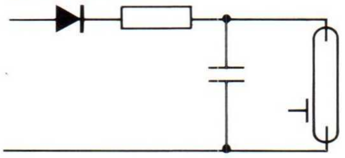
This results in the capacitor not being fully charged before it is discharged and hence reduces the energy per flash and consequently the mean power at the fastest repetition rates.

A small inductance L_1 is normally only required when metallised paper (MP) storage capacitors are used in order to reduce peak current.

Some possible charging circuits for the storage capacitor C_1 from an A.C. source are shown in figures 2a to 2g.

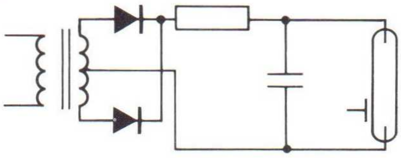
Figure 2 Charging Circuits

2a. Half-Wave Rectifier



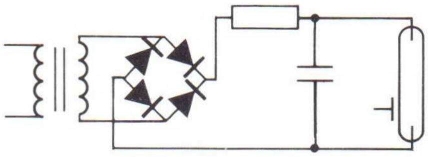
Low Power
Direct Conversion
Vc/Vin = 1.4
Low Ripple Frequency

2b. Full-Wave Rectifier



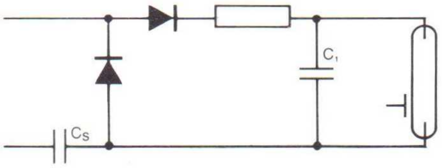
Higher Ripple Frequency
$V_c/V_{in} = 1.4$

2c. Bridge



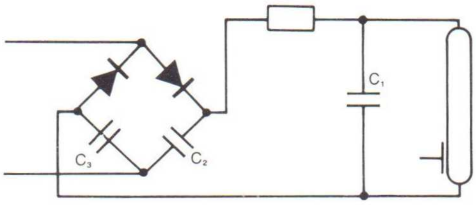
High Power Application
$V_c/V_{in} = 1.4$

2d. Doubler



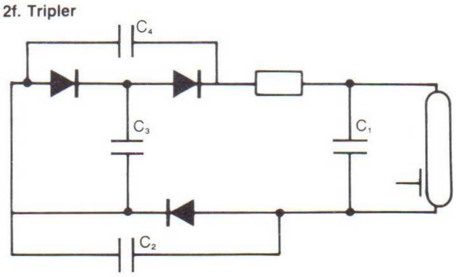
Low Power
$V_c/V_{in} = 2.8$
$C_s \gg C_1$

2e. Doubler



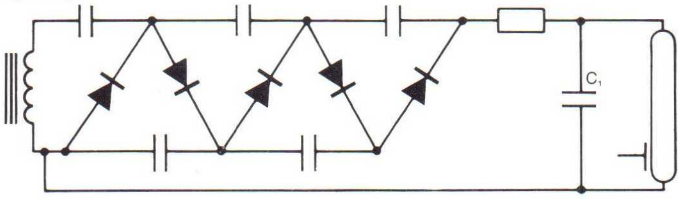
High Power Application
$V_c/V_{in} = 2.8$
$C_2 = C_3 \ll C_1$

2f. Tripler



Low and Medium Power Application
Typically
$C_2 = C_3 = C_4$ or
$C_4 = 2C_2 = 2C_3$
$V_c/V_{in} = 4.2$

2g. Multiplier



With n capacitors and n rectifiers, this circuit attains when unloaded n times the peak input voltage i.e. $V_c/V_{in} = 1.4\,n$.

Note: C_1 is not included in multiplier calculation.

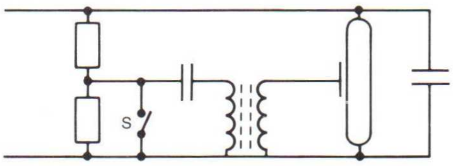
In figure 3 two methods of triggering the flash are shown. These are external triggering which is most commonly used for stroboscopic and photoflash applications and Series Injection Triggering which is a less common method but which has advantages in some applications. Table 1 compares the advantages of the two methods.

Table 1 Comparison of Flashtube Triggering Methods

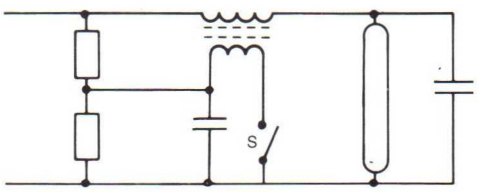
External Triggering	**Series – Injection Triggering**
Low cost	1. No exposed high voltage
Lighter and smaller	2. No high voltage across envelope which can discolour the glass
Less critical design	
Other circuit components do not have to withstand trigger voltage	3. More reliable at lower voltage
Secondary of trigger coil does not have to withstand main discharge current.	

Figure 3 Trigger Circuits

3a. External Trigger



3b. Series Trigger



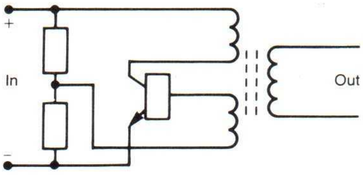
Note: "S" can be a switch, an SVP, a neon glow tube, an externally pulsed SCR or a thyratron etc.

3. Input Energy and Power

Figure 4 suggests several ways in which a low voltage D.C. (e.g. battery) can be converted to the higher voltage required to operate the flash tube, typically 350 VDC for a commonly used type of tube.

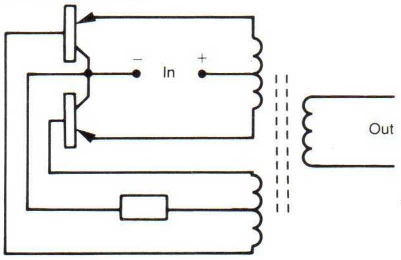
Figure 4 Converter Circuits

4a. Ringing Choke



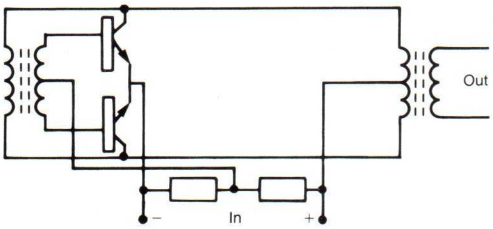
Most Efficient Converter Preferred for 1–5 Watt Loads

4b. Self-Saturating



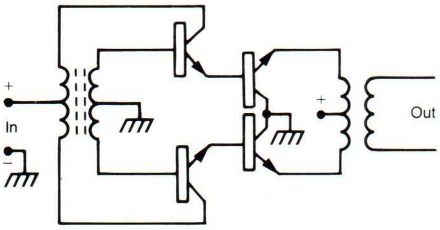
Reduction of Power Dissipation per Transistor (also P.I.V.) Generally used for 5–50 Watt Loads

4c. Two Transistor, Two Transformer



Generally used for 50–100 Watt Loads

4d. Two Transformer, Four Transistor



Generally used for 50–200 Watt Loads

A. The light output of a flash tube is a function of the electrical energy stored in the storage capacitor. This energy is given as:–

$$E \times \frac{1}{2} C (V_1 - V_2)^2$$

Where E = Energy in Watts seconds or Joules
C = Capacitance of storage capacitor in farads
V_1 = Flash capacitor potential in volts.
V_2 = Residual potential across flash capacitor after flash tube operated.

B. Average Power – The average power dissipated by a flash tube can be expressed as:

$$W_{avg.} = Ef$$

Where E = Energy in Watt seconds or Joules
f = Flash rate in Hz

It is important in flash tube design to consider not only the maximum energy per flash but also the average power. The flash tube has a maximum rate at which it can dissipate heat, and the heat produced by the flash tube is proportional to the average power.

What this means is that at higher flash rates the energy per flash must be reduced.

C. Instantaneous Power – Instantaneous power input to a flash tube is a function of the energy input and the pulse duration of the flash. Arithmetically this means:

$$W_{inst} = \frac{E}{t}$$

Where E = Energy in Watt seconds or Joules
t = Duration of flash between ⅓ power points

The instantaneous power is important in determining the visibility of the flash and is responsible for the "stop-action" feature of electronic flash guns.

4. Flash Duration

The duration of the flash is determined by the capacitance of the flash capacitor, the resistance of the flash circuitry, and the internal resistance of the flash tube. The type of flash capacitor is also of importance. Electrolylitic capacitors give longer flash durations because of their inherent internal impedance. Paper, paper and plastic or plastic type capacitors designed to have low internal impedance must be used if the shortest flash duration times are required.
An approximate relationship between flash duration and impedance can be expressed as:

$$\tau = RC$$

or, if an inductor is used:

$$\tau = \pi \sqrt{LC}$$

Where τ = Time interval between ⅓ intensity points
C = Capacitance of the flash capacitor in farads
R = Resistance of the circuitry and flash tube in Ohms
L = Inductance of the choke in Henrys

With Xenon flash tubes, light pulses from about 1 μs to 10 ms can be produced. Pulses much shorter than 1 μs are impossible because of the properties of flash capacitors and other circuit components.

In order to achieve a short pulse width with a give input energy, it is necessary to use a high voltage, a small capacitor, and a flash tube with low internal resistance.

For photographic applications, which generally require fairly long flashes of perhaps 1 ms, a large capacitance and low voltage are used in conjunction with a flash tube having a high internal resistance. High impedance tubes typically have impedances of about 1.5Ω while standard types have about 1Ω. Stroboscopic tubes have lower impdances in the order of 0.5Ω.

The value of this resistance depends on several parameters including gas pressure, tube diameter, and arc length.

Assuming all other parameters to be equal, the internal resistance of the flash tube is proportional to the arc length. Therefore, tubes designed for long pulses are generally of the coiled type, while those designed for short pulses are linear.

5. Efficiency

When a flash tube is used in conjunction with the proper circuitry, a conversion efficiency of as much as 50% can be achieved. This means that ½ of the electrical energy applied is converted into photon (light) energy.

Of greater importance to most flash tube users is the luminous efficiency of the flash tube i.e. how much light can be seen with the eye as a function of electrical power input.

Depending on the flash tube type and the application, luminous efficiency can vary between 5 and 50 lumens/Watt.

The highest efficiency flash tubes have a long arc length and are designed for high voltage operation.

The extremely short pulse widths of Xenon flash bursts increase the effective efficiency of the flash even further.

Compared to a flashing incandescent lamp with a given luminous output, a flash tube with the same output can have an effective intensity five times greater, (IES Guide for Calculating the Effective Intensity of Flashing Signal Lights). November 1964.

6. Spectral Output

Quantum theory states that only certain electronic transitions are possible within an atom, that the output spectrum of a Xenon flash tube should ideally be a group of specific wave lengths as opposed to broad-band radiation.

To some extent this is true – there are definite strong lines in the flash tube output, but other phenomena including pressure-broadening cause the output to be more or less spectrally continuous, and similar to daylight.

The Xenon flash tube emits light from roughly 0.2 microns in the UV to about 2.0 microns in the near IR, and has peaks at about 0.48 microns and 0.8 microns. The visible region of the spectrum falls roughly between 0.4 microns and 0.7 microns.

The colour temperature normally corresponds to a black body at between 6000.K and 7000.K.

When current density through the flash tube is decreased, there is spectral shift towards longer wave lengths (red).

The current density is dependent upon the tube diameter, the input energy to the tube, and the capacitor discharge time.

Where ultraviolet radiation is required, a quartz envelope should be used. Quartz transmits UV down to about 0.2 microns, while hard glass transmits only to 0.32 microns.

Note that for photographic purposes the UV radiation is undesirable, and glass envelopes are normally used unless some method of external filtering is employed.

7. Flash Tube Life

The life of a flash tube, depending on how it is used, can range from one shot to many millions of shots.

For applications where long life is important, the flash tube should be operated well below its maximum rated energy.

The two basic causes for flash tube failure are as follows:

A. As the tube is flashed, ions and electrons bombard and scatter electrode material, and this material is then deposited on the inner surface of the tube. Blackening occurs, which reduces light output and decreases the electrical resistance of the tube. Eventually, the tube will fire irregularly and, finally fail completely.

B. When peak current is too high, fine cracks can form in the tube envelope, or worse, the pressure wave formed in the Xenon gas can shatter the tube completely. For this reason, care should be taken never to exceed the maximum tube rating. With low voltage tubes using metallised paper capacitors, a resistor or choke should be inserted between the tube and the flash capacitor to reduce pak current.

The power that a flash tube can tolerate is a function of the envelope material used, the tube shape and arc length, and the duration of the flash.

Quartz tubes will tolerate the highest loading, but even so, the flash energy must be reduced when ultra short pulse width are required.

8. Photometric Units – Derivation of Standard Terms

Take the standard whale blubber candle, which, by definition has a light output of 1 candle power.

Also by definition, the luminous flux emitted by the candle is 1 lumen per steradian.

Since the candle is assumed to emit uniformly in all directions we can thus say that 1 candle power is equivalent to 4π lumens.

If a lumen of flux is distributed over a 1 sq.ft. area, the light intensity is called a foot-candle (fc), i.e.:

1 ft. candle = 1 lumen/ft.^{2}

What this means is that the intensity of our candle at a distance of 1 foot is:

$$\text{ft. candles} = \frac{4\pi \text{ lumens}}{\text{area of sphere with radius of 1 ft.}}$$

$$= \frac{4\pi}{4\pi\ r^2} = \frac{1}{r^2} = 1 \text{ ft. candle}$$

where r = distance from the candle

similarly, at a distance of 2ft., the intensity of 0.25 ft. candles.

When discussing light sources, the term horizontal candlepower (HCP) often comes up. HCP refers to the intensity of light in a particular direction – usually perpendicular to the axis of symmetry. It can be expressed arithmetically as:

$$\frac{HCP}{r^2} = fc$$

where fc = lumens/ft^2 (foot candles) intensity at distance r.
r = distance from source in ft.

One other common unit, beam candlepower (BCP), refers to a light source/reflector combination where the light is re-directed into a "beam". Very simply, this value is expressed as:

$$BCP = HCP \times M$$

where M = reflector "amplification" factor

When one is concerned with flash tubes, where input energy is normally given in watt seconds, people often talk in terms of lumen seconds instead of lumens.

This is really no problem because the other units change accordingly, i.e.:

Candlepower becomes candle power seconds
Lumens become lumen seconds
Foot candles (fc) become foot candle seconds (fcs)
HCP becomes HCPS
BCP becomes BCPS

Taking the expression ...

$$HCP = (fc) \times (r^2)$$

And adding seconds we get ...

$$HCPS = \text{ft. candle seconds} \times (\text{distance from flash tube})^2$$

or

$$HCPS = (fcs) \times (r^2)$$

Similarly, we get ...

$$BCPS = (fcs) \times (r^2)\ M$$

The total output can thus be expressed as ...

$$Q = 4\ r^2\ W$$

Where Q = total lumen seconds output
r = distance from flash tube in ft.
W = ft. candle seconds

It has been shown that empirically (especially in the case of helix tubes)

$$Q \approx 10\ r^2\ W$$

This of course, is not so unreasonable, since flash tubes are not point sources and their output is not spherically symmetrical.

9. Electronic Flashgun for Photography – Sample Calculation

For the portable flashgun a small linear flash tube with an appropriate reflector porvides the optimum in efficiency and uniformity of output.

Suppose we use a CG 4330 flash tube and operate it at 360 volt anode potential in conjunction with a 930 μf capacitor. The input energy to the tube is then

$E = \frac{1}{2} CV^2$ (Ignoring residual voltage on capacitor)

$= \frac{1}{2} (930 \times 10^{-6}) (360)^2$

$=$ 60 Watt seconds per flash

To estimate the light output of the flash tube, we need to know the efficiency (see section 5). Although a value of 35 lumens/Watt is a conservative Rule-of-Thumb, for linear photographic tubes a more realistic efficiency is 40 to 45 lumens/Watt ... we'll use 40. Therefore,

$Q = E \times \eta = (60) \times (40) = 2400$ lumen seconds

Where Q = Light output in lumen seconds
E = Input energy in Watt seconds
η = Efficiency in lumen seconds/Watt second (which is the same as the efficiency in lumens/Watt)

From Section 8 we recall that

$$HCPS \approx \frac{Q}{10}$$

or $HCPS \approx 240$

Good photographic reflectors designed for standard camera lenses typically have "amplification" factors between 6 and 8. Being conservative, and solving for the beam candlepower seconds output of the flash tube reflector combination

$BCPS = M \times HCPS = (6) \times (240) = 1440$

For photographic applications, the BCPS value is very useful. From it can be derived the standard guide number used in all photoflash equipment, because

$$rA = \sqrt{(BCPS)} \; \frac{S}{C} = \text{Guide Number}$$

Where r = Subject to flash tube distance in feet
A = Lens aperture or f/# number
S = Film sensitivity or "Speed", i.e. the ASA number
C = Constant somewhere between 15 and 20. We will use 20

Let's assume we want to use Kodachrome II film with an ASA of 25. Then,

$$\text{Guide Number} = \sqrt{\frac{(1440)\,(25)}{(20)}} = 42$$

Since, by definition, the guide number is the product of the aperture and the subject distance

$(f/\#) \times (r) = 42$

or $(f/\#) = \frac{42}{r}$

What this all means is that with this particular tube reflector combination, in order to take a photograph at a distance of 23 feet from the subject, the camera aperture must be opened to f/1.8. Likewise, at a distance of 2.6 feet the aperture must be f/16.

10. Emergency Beacon Sample Calculation

Suppose we consider a Beacon Flash Tube such as the CU 4668 and want to operate it at 500 volts anode potential with a 100 μfd capacitor. Let's also assume that the required repetition rate is one flash per second.

The input energy to the flash tube is:–

$E = ½ CV^2$ (Ignoring residual voltage on capacitor)

$= ½ (10^{-4}) (500)^2$

= 12.5 Watt seconds per flash

and the average power is then

$W_{avg} = E \times \text{frequency} = 12.5 \times 1 = 12.5$ Watts

Both energy and power are well within the operating limits of the CU 4668.

Next, the output of the tube can be estimated (by assuming a conversion efficiency of 35 lumen second/watt second) to be

Q = 12.5 Ws × 35 lumen seconds/WS

= 438 lumen seconds

or about 44 HCPS

Typically, a beacon tube will be encased in a dome, configured in such a way to act as a Fresnel lens.

There is a question as to the usefulness of this type of lens, particularly at great distances, but for the sake of calculating let's assume we get an "amplification factor" of 1.5.

Remembering that the product of this "amplification factor" and the HCPS value gives us the BCPS ...

BCPS = 44 × 1.5 = 66

This BCPS value, however real, does not give an accurate comparison between the flash tube and, say, an incandescent lamp, because of the extremely short pulse duration of the flash tube.

By referring to the IES article previously referred to in Section 5 we find that

$$I_{eff} = 5 \int_{t_1}^{t_2} I dt$$

Where I_{eff} is the effective intensity of the tube, and the integral is simply the total light output of the flash. Therefore,

$I_{eff} = 5 \times 66 = 330$ BCPS

To put it another way, the CU 4668, operated under the previously specified combination, will have an output of about 330 effective candle power seconds (ECPS).

11. Miscellaneous Features of Flash Tubes

1. Better electrical to light conversions
   a. Incandescent lamps typically operate at 10% efficiency, never more than 40%
   b. Xenon flash tubes often reach 50% efficiency
2. Better visibility, particularly at great distances and under adverse weather conditions (see IES article)
   a. A flashing light is easier to see than a continuous source. It attracts attention.
   b. Even when an incandescent lamp is flashed the inherently long pulses make it much less effective than the flash tube. This is due to the fact that the eye integrates signals every 30 milliseconds, and thus receives the entire output from the flash tube in one burst. On the other hand, the output from the incandescent lamp us divided over several eye integration periods, thereby reducing the effective brightness to the viewer.
3. In flash tube beacons there are no moving parts to wear out such as the required motor in a rotating beacon which can require as much as 100 watts to drive it.
4. Incandescent lamps burn out very quickly when flashed and do not normally last more than 2000 hours when operated continuously. For virtually all pulse applications the flash tube will outlive an incandescent source.
5. In the majority of applications the flash tube combined with circuitry offers an advantage in size and weight over other light sources.
6. The Xenon flash tube is ideal for colour (as well as black and white, of course) photography.
   a. The Xenon spectrum from a flash discharge is close to that of sunlight, thereby allowing the photographer to use daylight type film indoors.
   b. The incandescent lamp spectrum is far too red for daylight film. Therefore, either special film or filters must be used with this light source.
   c. The extremely short pulse width of the Xenon flash allows "stop action" photography even with slow shutter speeds.
7. In many applications, flash tube systems can give an overall cost saving compared to other light sources.

12. Typical Applications

Siemens offer a complete range of Heimann Xenon Flash Tubes for which typical applications are:

A. Flashing Beacons for Guidance, Warning Indicators and Rescue Guidance

1. Satellite, aircraft and ship beacons
2. Lighthouse and airport beacons
3. Emergency vehicle beacons
4. Hand held rescue and signal beacons
5. Sources for IR night vision equipment
6. Sources for optical guidance systems
7. Trafflic signals
8. Burglar Alarm

B. Stimulation of Pulsed Lasers

1. Pumping Neodymium rod lasers
2. Pumping of Ruby rod lasers
3. Pumping of Dye Lasers

C. Stroboscopic

1. Automobile timing lights
2. Dynamic balancing equipment
3. Vibration analysis
4. High speed motion analysis
5. Photoelectric tachometers

D. Photography

1. High speed photography
2. Electronic photoflash units
3. Night photography i.e. IR film with flash tube behind visible light filter
4. Underwater photography
5. High speed cinematography

E. Office Copying Machinery

1. Light source
2. Heat source for powder setting

F. Advertising

1. High peak intensity attracts attention
2. Pulsing attracts attention

G. Miscellaneous

1. Spectroscopy
2. Fluorescence studies
3. Photochemical
4. Opto-medical
5. Discos

In addition a complete range of trigger transformers, capacitors, reflectors etc are available for use in associated circuit.

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