APPLICATION NOTE

LIGHTING SOLUTIONS

High Performance Flash!
by PerkinElmer

Fundamentals

Electronic flashtubes are gas discharge devices for pulse operation. Xenon is used as a fill gas for most applications. For laser excitation Krypton is also used.

Modes of Operation

- Single flash: Random request for single flashes. In comparison to the flash duration (normally between 10 µs and 10 ms), the off times are very long, typically a few seconds.
- Stroboscopic and beacon operation: The discharges are produced periodically and often over a longer period of time. Typical stroboscopic frequencies are between 1 Hz and several kHz. Higher frequencies require special flashtubes and circuits.
- Continuous wave discharge: Electronic flashtubes are unsuited for this mode of operation.

Authors
Ingo Dünisch
Peter Strzelczyk
Dr. Rainer Heise
PerkinElmer Optoelectronics
Wenzel-Jaksch-Str. 31
65199 Wiesbaden
Germany

Configuration

All flashtubes consist of a tube made of hard glass or quartz glass with sealed-in electrodes (anode / cathode) at each end. In addition to linear glass tubes, various other shapes, such as U, ring, or helix shape are also available. The cathode contains emitter substances to reduce the electron work function. When connecting flashtubes, polarity must be observed. Non-polarized tubes with two cathodes are also available.

Many flashtubes are equipped with a capacitive trigger electrode -- for example, a wire wrapped around the tube, a silver stripe or a transparent conductive coating on the outside of the glass.

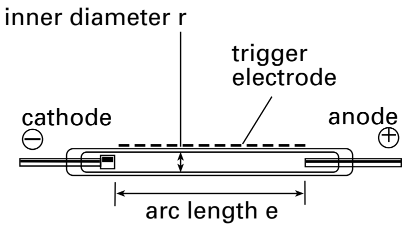
Leads on electrodes can be supplied with solid or flexible lead wires, according to PerkinElmer standards or customer specifications. Lamps can also be supplied with sockets, end caps and protective covers.

Flashtubes are light sources with high power density. Therefore, they are only made of high temperature resistive materials.

Discharge tube characteristics

Apart from the glass material and electrodes, flashtubes feature three key characteristics:

1. The arc length (e)
2. The inner tube diameter (r)
3. The Xenon (or Krypton) fill pressure (p)



Schematic drawing of a flash tube

By determining e, r, and p, all conditions and requirements such as flash energy, expected life, trigger quality, size, optical projection and spectral distribution of the light must be fulfilled.

Tubes characterized by low e/r ratios (typically e/r < 5) are called electrode stabilized and used for short pulses and high luminance. The plasma is mainly guided by the anode and the cathode tips – not touching the glass.

For tubes characterized by higher e/r ratios, two typical flash discharges have to be distinguished:

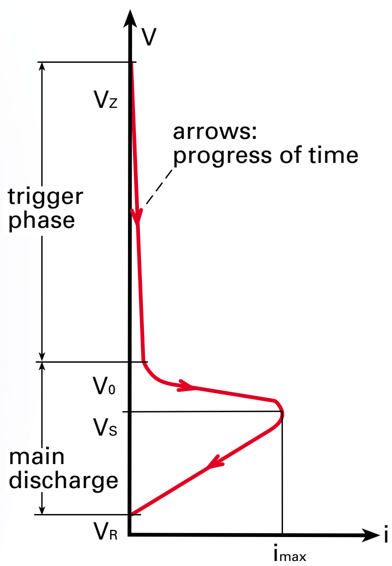
- The plasma fills the cross section of the tube completely, limiting the peak current. The discharge is referred to as "wall stabilized." Most flashtubes are designed for 5 < e/r < 20, as this range obtains the best light efficiency.
- Typically, for stroboscopic applications the plasma does not fill the tube cross-section completely, but is guided along the glass envelope. The flash capacitor or an electronic circuit limits the peak current.

The luminous efficiency rises with an increase in Xenon fill pressure, whereas the ability to trigger the lamp decreases inversely.

Discharge sequence

Flashtubes are connected with two different electronic circuits:

1. The trigger circuit: operates in the trigger phase.
2. The main discharge circuit: operates in the main discharge phase.



The impedance characteristic of the flash discharge

The impedance characteristic – anode voltage (V) versus discharge current (i) – features the same form for all flash discharges. Its slope represents the characteristic of the discharge.

First, the trigger voltage V_z (typically 2 to 20 kV) causes an ionization in the tube. This requires energy (typically 1 to 100 mJ) and time (typical trigger delay is 1 to 10 µs).

The main discharge can be subdivided into the current rise and the current decay. During the decay phase, under normal conditions, most of the light output is generated. The following internal impedance of the tube R_i can be defined as:

$R_i = V_S / i_{max}$
(typical 0.1 to 5 Ohms)

Finally, the discharge extinguishes at a residual voltage of V_R (typically 10 to 100 V).

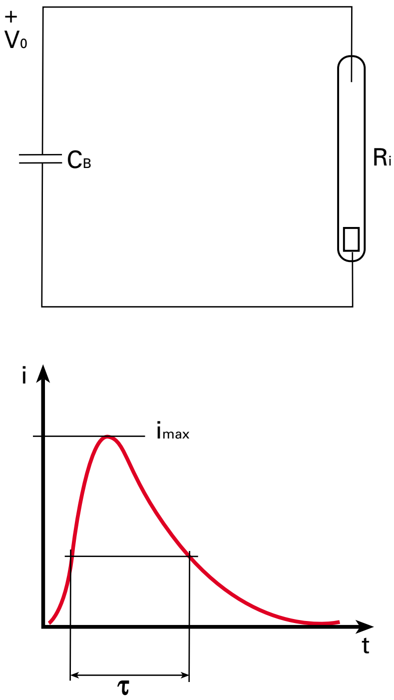
Main discharge circuits

Free capacitor discharge

The energy E [J] stored in the flash capacitor C_B [F] at an operating voltage V_0 [V] is defined as:

flash energy $E = \frac{1}{2} C_B V_0^{\,2}$

A low percentage of residual energy in C_B is neglected when the discharge extinguishes.



Free capacitor discharge

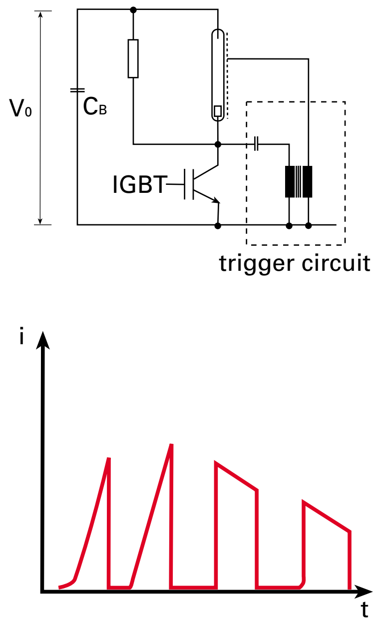
After the peak current i_{max} has been reached, an almost exponential discharge of C_B takes place, since the internal resistance R_i of the tube remains constant. The time constant $\tau = R_i C_B$ is a measure for the flash duration (~ 1/3 value).

In stroboscopic applications, the tube's medium power load P [W] results from the energy E [J] of the individual pulse and the repetition rate f [Hz]

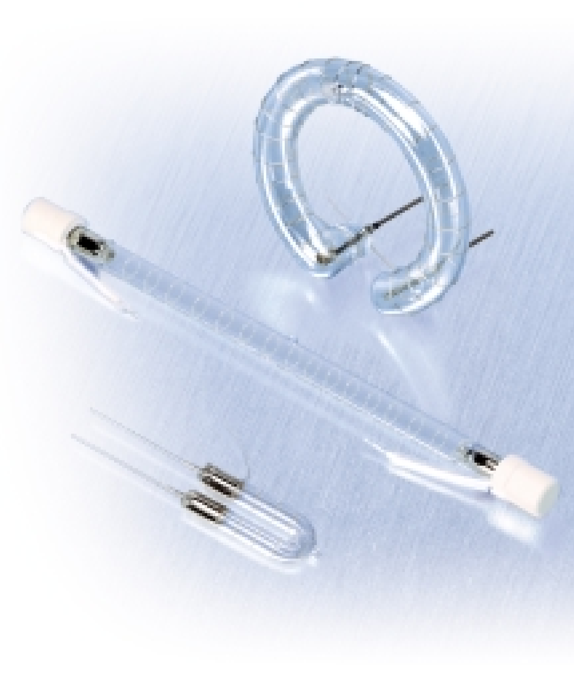
$P = E * f$

Discharge control by semiconductor

An IGBT offers high peak current and high frequency switching with very low loss and a simple driving circuit. This concept is ideal for discharge control of flashtubes. The IGBT can also operate the lamp's trigger circuit. All pulse patterns, preflashes and any manipulations of the mainflash are possible.

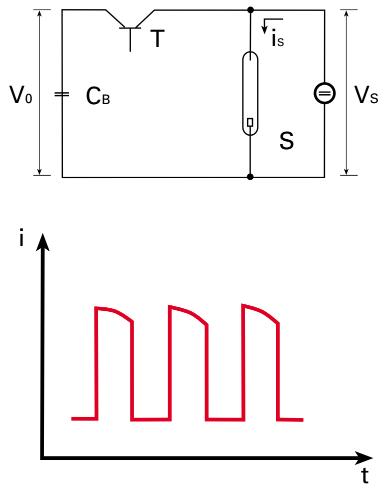


IGBT charge control



Simmer operation

The constant current source (S) maintains a simmer current in the lamp. When the semiconductor (T) is operated, any pulse discharge pattern can be superimposed to the simmer current without an additional high voltage trigger impulse. The simmer current should be rather small, but must be adapted to the lamp's requirements.



Simmer operation

Trigger circuits

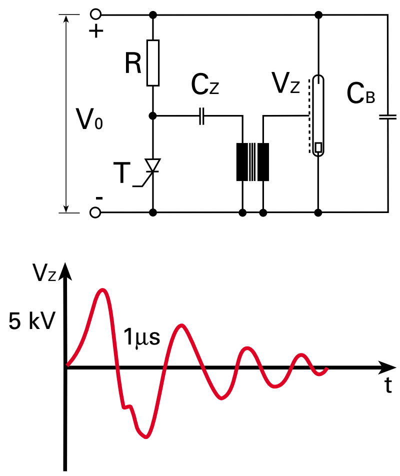
The flashtube discharge is initiated by means of a high voltage pulse Vz (trigger voltage) which must be higher than the static breakdown voltage of the tube.

Typical V_z values range between 2 kV and 20 kV. The difference between V_z and V_0 must be sufficient to avoid spontaneous triggering.

V_z is generated by a pulse transformer (trigger coil). Typical transformation ratios are 1:20 to 1:100.
A semiconductor or mechanical switch discharges a trigger capacitor C_z via the primary side of the trigger coil. On the secondary side a damped high voltage oscillation is produced. The oscillation frequency, amplitude and damping depend strongly on the trigger coil and the external circuitry.

1. Capacitive external triggering

This is the simplest form of triggering. The trigger electrode of the tube is insulated from anode to cathode and extends over the entire arc length.



Capacitive external triggering

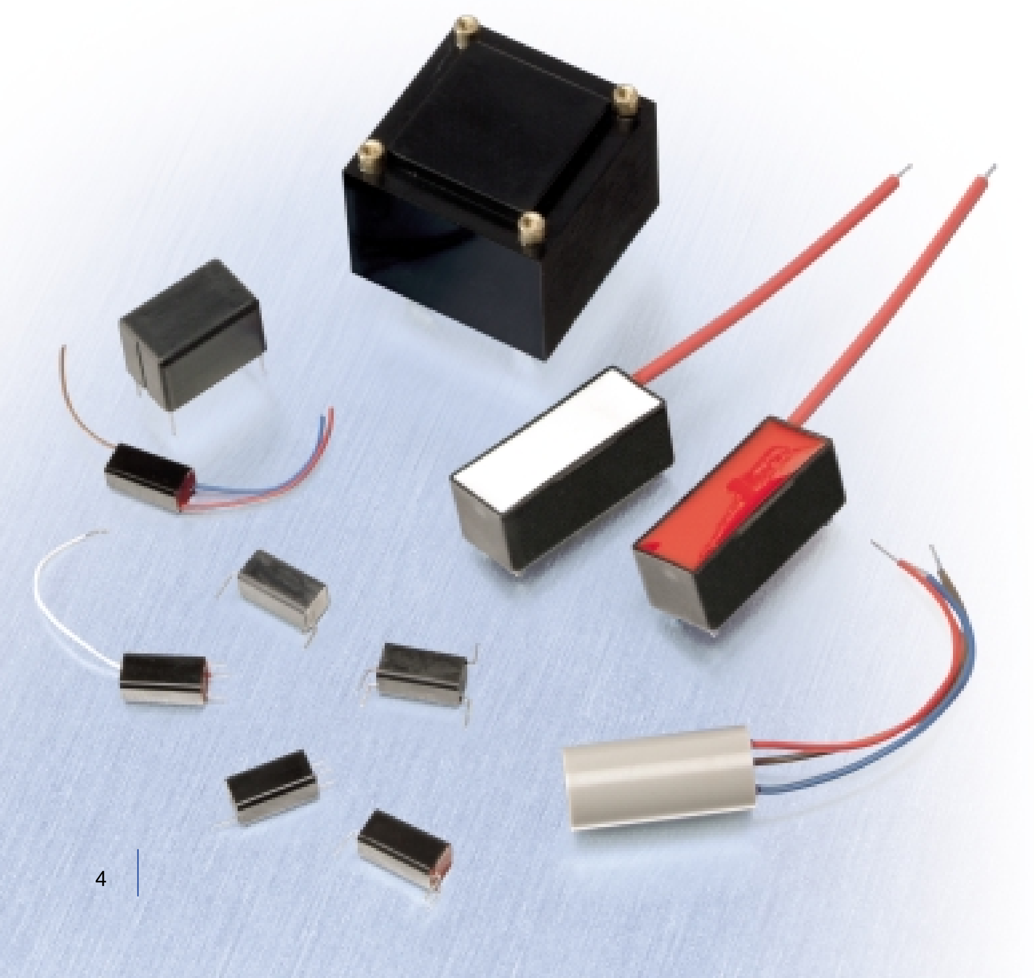
Since the capacity of the trigger electrode is in the range of some pF against the cathode and anode, the secondary side of the trigger coil can be highly resistive, resulting in a compact construction of the coil.

The polarity of the first half wave of the high voltage trigger oscillation can influence the ability to trigger.

Advantages of external capacitive triggering are:

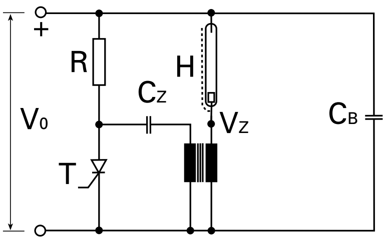
- Low primary and secondary currents.
- Small size, low cost components.

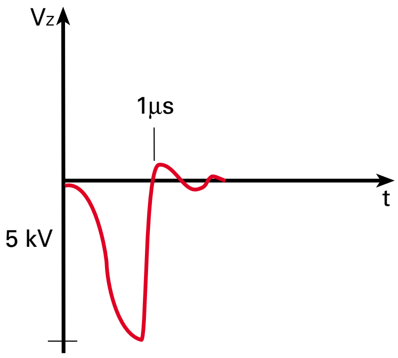
One disadvantage of the external triggering is the production of electromagnetic interference, especially in the case of long wires within the trigger circuit.



2. Direct series triggering

The secondary winding of the trigger coil is either on the anode or cathode side, in series with the lamp, and conducts the entire discharge current.





Direct series triggering

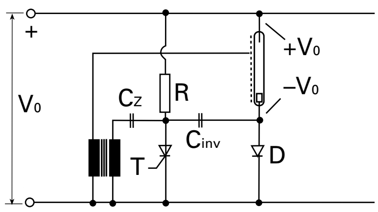
There is no need of an isolated trigger electrode extending over the arc length. In special cases, an optional trigger electrode can be connected with the anode or cathode.

In comparison to the capacitive external triggering, the advantage of direct series triggering is shorter trigger delays and lower emission of electromagnetic interferences. Some disadvantages of direct series triggering include the larger size and higher cost of components.

PerkinElmer trigger transformers for external and series triggering are included in this application note.

3. Trigger with doubling of anode voltage

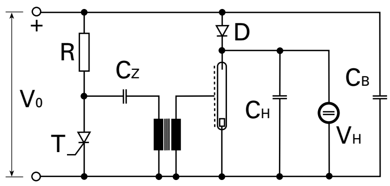
This circuit considerably improves the triggering ability of flashtubes with high gas fill pressure. When firing the thyristor T, the discharge of C_Z produces the usual high voltage trigger oscillation in the secondary trigger coil. Simultaneously, C_{inv} is discharged, bringing down the cathode potential of the flashtube to $-V_0$ for a few microseconds. Ideally, this doubles the effective anode voltage for triggering.



Trigger with doubling of anode voltage

4. Booster circuit

The booster is an auxiliary anode voltage $V_H > V_0$ which is applied to a capacitor $C_H << C_B$ and is blocked against V_0 by a diode D. The effective anode voltage for triggering is V_H. This circuit is ideal in cases of high variations in the operating anode voltage or when the fill pressure is high.



Capacitive triggering with additional booster

Generation of light by Xenon discharge

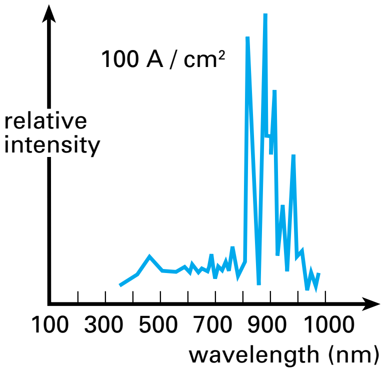
Within the group of discharge lamps, flashtubes fall into the category of high-pressure arc lamps. Xenon fill pressures of 50 to 3000 Torr and current densities between 100 and 10000 A/cm² provide all the characteristics of an arc discharge :

- Plasma temperatures between 7000 to 10000 K.
- A continuum radiation, very similar to sunlight.
- Among the noble gases Xenon has the highest photometric radiation efficiency – approximately 40 lm/W.
- Xenon flashtubes have the highest luminance of all light sources, apart from lasers.

In flashtubes, the Xenon spectrum consists of a continuum – the distribution to the radiation of a black body and a characteristic line spectrum – that mainly contributes to the infrared region between 880 to 1000 nm.

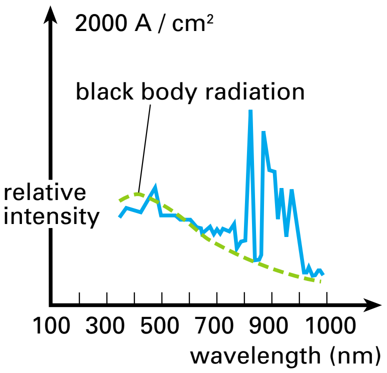
The density of the discharge current specifically influences the relation between lines and continuum. By determining this current density, the portions of UV and IR radiation added to the visible light can be selected. It is not possible to emit “colored light“ only. This applies for other inert gases as well.

Current densities in the range of several hundred A/cm² can only be achieved in tubes with high internal impedance. In this case, the portion of IR radiation is strongly predominant.

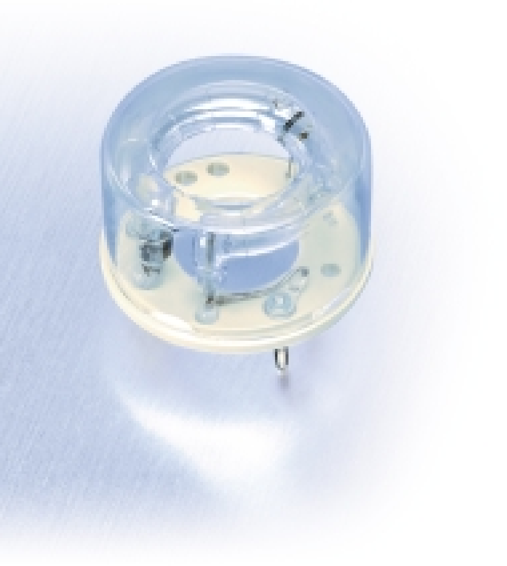


Spectrum of a high impedance flashtube

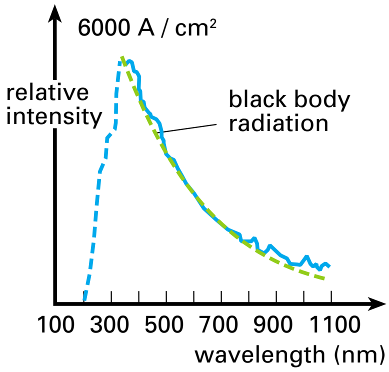
Current densities of 1000–3000 A/cm², used in most studio, beacon and stroboscopic flashtubes, feature IR as well as a strong continuum. UV radiation can also be considerable.



Spectrum of a studio flashtube

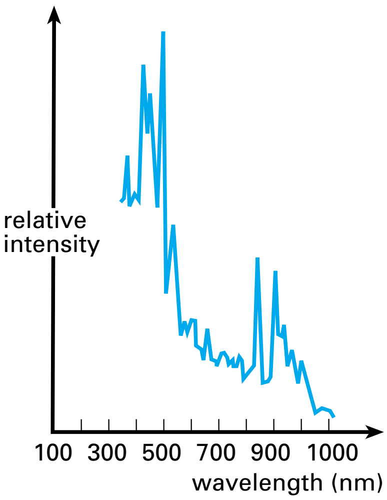


Current densities between 4000–10000 A/cm² feature minimal IR lines. The continuum is now very similar to sunlight (7000 K). These tubes provide the highest visual radiation efficiency (up to 40 lm/W), particularly in photo flashtubes.



Typical spectrum of a photo flashtube

The large portion of UV and blue in the spectrum of these tubes can interfere with photographic applications, but can be corrected through filtering.



Spectrum of a short arc flashtube

Short arc lamps with very hot as well as very cold plasma zones due to the missing wall stabilization can have IR lines, UV lines and a distinctive continuum.

Envelope materials

Flashtubes are divided into two groups, classified by power:

- Hard glass tubes.
- Quartz glass tubes (withstand three to ten times more power than hard glass tubes).

1. Hard glass

There are four borosilicate glasses, selected and characterized by their exceptional resistance to the arc and by optical quality.

Borosilicate glass B1 (standard glass):

- Automatic processing ability.
- Many tubes diameters available.

Borosilicate glass B2:

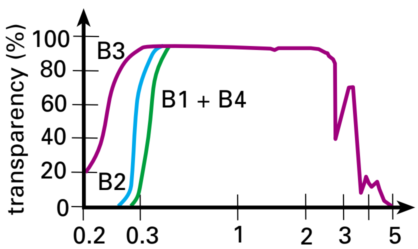
- Withstands approx. 30% more power than B1.
- Requires manual processing.

Borosilicate glass B3:

- Extra transparency for UV radiation.
- Automatic processing ability, similar to B1.

Borosilicate glass B4:

- Automatic processing ability.
- Allows up to double flash energy in photoflash applications compared to B1.



Transparency of borosilicate glasses

2. Quartz glasses

Quartz glass gains its unique resistance to arc and thermal shock from the high bonding energy of pure SiO_2 and the negligible small expansion of 4 x 10^{-7}/K. Quartz glass usually requires manual processing.

Quartz glass Q1:

- UV transparent.

Quartz glass Q2:

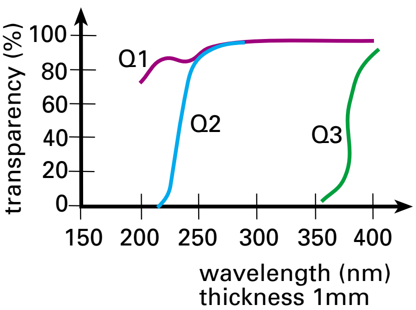
- Reduced generation of ozone.

Quartz glass Q3:

- No generation of ozone.

Quartz glass Q1, Q2 and Q3 differs mainly in their UV transparency.

Synthetic quartz glass is available on request.



Transparency of quartz glasses

Color corrective coatings and colored lamps

Hard glass and quartz glass can be coated with a yellow layer that absorbs the excessive blue radiation for film exposure. The color temperature is lowered by 1000 to 2000 K.

For special applications, flashtubes can be colored with uniform and crack-free colored layers. Typical colors are red, blue, amber, green, and purple.

Life expectancy

Flashtubes age in terms of light output reduction and decreased ability to trigger the lamp. Statements on the life of a specific flashtube require exact knowledge of the following operating conditions:

- flash energy,
- anode voltage,
- flash frequency,
- flash capacitor and its effective series resistance,
- resistors and inductances in the discharge circuit,
- reflector,
- cooling conditions,
- criteria defining the end of life.

All details of the life expectancy mentioned in the catalog refer to nominal operating conditions that are described in the individual specifications.

The flashtube drawings shown on the following pages are schematic sketches only. Further details, as well as tolerances of the mechanical dimensions, are provided in our data sheets, available on request.

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European Headquarters
PerkinElmer Optoelectronics
Wenzel-Jaksch-Str. 31
65199 Wiesbaden, Germany
Telephone: (+49) 611-492-269
Fax: (+49) 611-492-132
Email: opto.Europe@perkinelmer.com

Asia Headquarters
PerkinElmer Optoelectronics
47 Ayer Rajah Crescent #06-12
Singapore 139947
Telephone: (+65) 67704-306
Fax: (+65) 67751-008
Email: opto.Asia@perkinelmer.com

Worldwide Headquarters
PerkinElmer Optoelectronics
44370 Christy Street
Fremont, CA 94538-3180
Telephone: +1 510-979-6500
Toll free: (North America) +1 800-775-OPTO (6786)
Fax: +1 510-687-1140
Email: opto@perkinelmer.com
www.optoelectronics.perkinelmer.com

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