Electronic lamp control gear

4.1 Electronic high-frequency system

4.1.1 Block diagram (see Fig. 43)

The main functions of a ballast have been described in Section 2.1: Main ballast functions.
Although the electronic HF ballast system is integrated into one single 'black box', its different functions can be divided into a number of individual blocks. In broad outline: after passing a low-pass (RFI) filter, the mains voltage is rectified in an AC/DC converter. This converter also contains the buffer capacitor, which is charged with current via this DC voltage. In the DC/AC converter the DC voltage is transformed into an HF voltage, which provides the power for the lamp controller. The ballast controller controls all these functions.

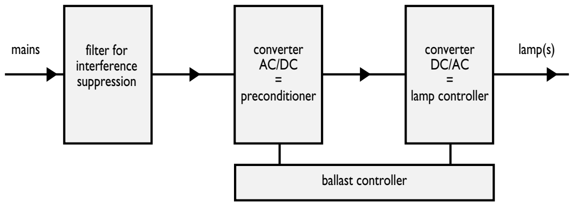

Fig. 43 Block diagram indicating the main functions of an electronic HF ballast system.

4.1.2 Circuit diagram (see Fig. 44)

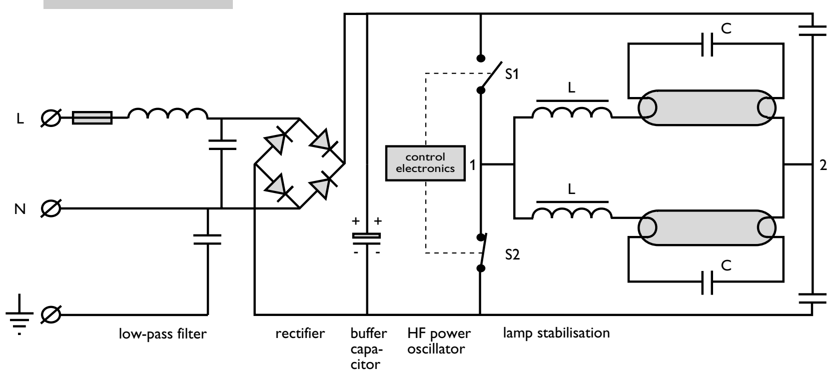

Fig. 44 Circuit diagram of an electronic control system (version with two lamps in parallel).

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The low-pass filter has four functions:
- Limitation of the harmonic distortion, so that its level remains within international standards (see Fig. 45).
- Limitation of radio interference, which would otherwise be injected from the HF ballast into the mains. Here also international standards are to be adhered to.
- Protection of the electronic components against high mains voltage peaks.
- Inrush current limitation.

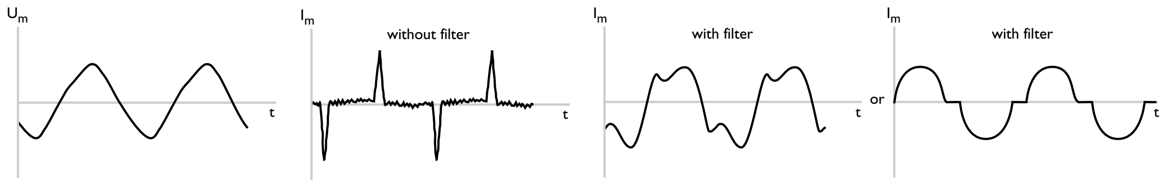


Fig. 45 Mains voltage and mains current, the latter without and with low-pass filter.

The low-pass filter is fully electronic (HF-P, HF-B, HF-R). The different functions (low-pass filter, RFI suppression, inrush limiter and transient limiter) are separated (see Fig. 46).
The advantages of the fully electro-nic version compared with the older 'split' version with a separate filter coil, include: it is smaller, lighter, has a high power factor, the light output is independent of mains-voltage fluctuations, and there is no 50 Hz hum.

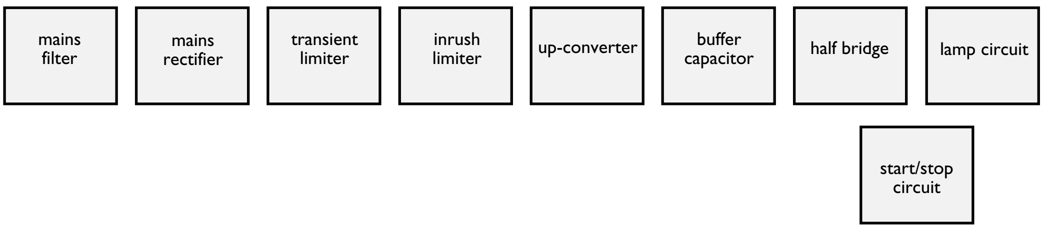


Fig. 46 Fully electronic and integrated low-pass filter.

The rectifier consists of a full diode bridge. The buffer capacitor in principle determines the shape of the lamp current and the mains current. It has to be chosen carefully in order to minimise the modulation in the lamp current (and thus the modulation in the light output). With a 'high' capacitor value the modulation in the light output is less than with a 'low' capacitor value, but the mains current waveform is more distorted (less sinusoidal), resulting in higher harmonic distortion (see Fig. 47).
Furthermore, the level of the inrush current depends on the value of this buffer capacitor.
The HF power oscillator is the heart of the electronic ballast. Controlled by the ballast controller the semiconductor switches S1 and S2 (Fig. 44) are switched at a frequency ranging from 30 to 100 kHz, so creating an HF square-wave voltage between the points 1 and 2.
The frequency is regulated by the ballast controller.
The controller contains all necessary sensors and intelligence to manage the mains input and lamp output functions of the electronic ballast, such as the preheating process, lamp power, stop circuit or safety switch-off, mains voltage fluctuations and mains frequency variations and sometimes over-voltage detection.

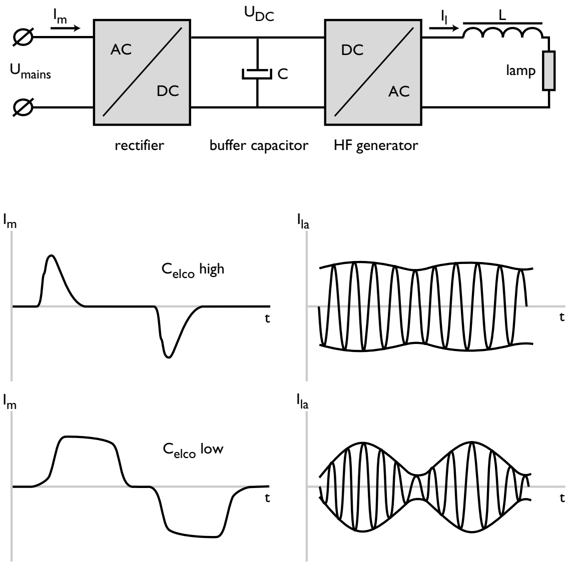


Fig. 47 Circuit with rectifier, energy buffer and HF generator. The curves show the lamp and mains current at high and low capacitance of the energy buffer for a typical CFL lamp.

The HF square-wave voltage is fed to the series connection of the lamp and the HF choke coil L (stabilisation coil). In the twin-lamp parallel version both lamp branches are connected in parallel with a choke coil for each lamp (Fig. 44). In the twin-lamp series version and in the single-lamp version, there is only one branch between the points 1 and 2 with one choke coil (see Fig. 48).

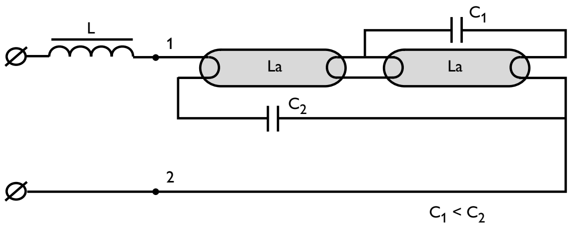


Fig. 48 Twin-lamp series version with only one branch between the points 1 and 2 with one choke coil.

Capacitors connected in parallel to the lamps are necessary for, among other things, the preheating and starting process: during preheating the current flows through the lamp electrodes and through these parallel capacitors.

4.1.3 Choice of frequency

As described in Section 3.4 the operating frequency should be above 10 kHz for 'TL'D lamps to obtain 10 per cent more efficacy, compared with the 50 Hz operation, and above 20 kHz to be above the human threshold of audibility. On the other hand, it should be below approximately 100 kHz to limit the losses in the ferrite coils and transistors.

Apart from these considerations there is a third factor to be considered: like all lamps, fluorescent lamps emit not only visible light, but also have a variable amount of infrared emission. Modulated in a high frequency, this can disturb infrared remote controls as used for television sets, audio, video, transmission systems and data communication. The lowest practical frequency for these systems is found in the RC5 system, working on 36 kHz. So the operating frequency for HF fluorescent lamps should not be 18 kHz or 36 kHz. Nowadays the frequency range from 30 kHz to 40 kHz is more or less reserved for IR systems. It is for this reason that various operating frequencies have been chosen for the newer generation of HF ballasts: an operating frequency of about 45 kHz was chosen for the HF-B types, for the PL*E/C system because the distance between lamp and ballast is normally short, and for the HF-R types to create a wide frequency band for dimming purposes (42-90 kHz).
On the other hand, one of the reasons for using an operating frequency of 24-31 kHz for HF-P ballasts is to minimise influences on EMC and to achieve maximum lamp cable capacities (see Sections 2.3 and 4.1.19).
The e-Matchbox operates at about 28 kHz.

4.1.4 Ignition and re-ignition

As described in Sections 3.3 and 3.4 a fluorescent lamp with cold cathodes needs up to an ignition peak voltage of more than 800 V r.m.s. depending on the lamp type, which means 1500 V top value. Due to this cold starting process emitter material will sputter away from the lamp electrodes. Frequent switching will thus result in a noticeably shorter lifetime. Another possibility is to bring the lamp electrodes up to their emission temperature before ignition by means of preheating. This is done by applying a frequency different from the operating frequency (normally higher) to the LC starting circuit for about 1.4 second to ensure a low open circuit voltage during the preheat phase (approx. 250 V) and a sufficiently high preheat current (see Figs 49 and 50).

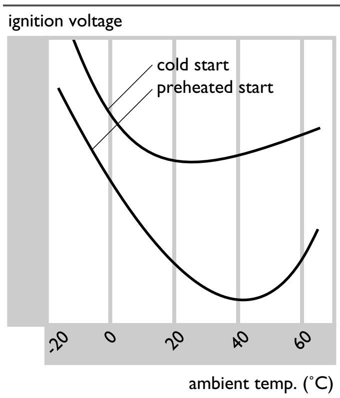


Fig. 49 Required ignition voltage as a function of the ambient temperature with preheated and non-preheated electrodes.

After the preheat time, a voltage of approx. 500 V (depending on the lamp type) is applied, again by changing the frequency, sufficient for reliable ignition during a maximum of approx. 0.2 second. The lamp ignites at the first ignition peaks and then the ignition voltage stops. After the preheat and ignition phase, the lamp gets its normal operating voltage (between approximately 50 V and 200 V, depending on the lamp type).

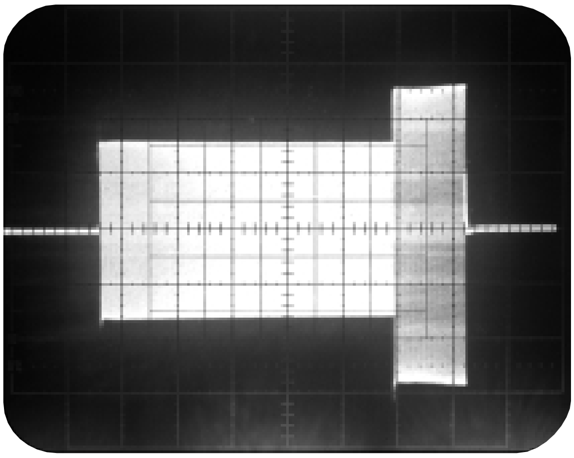


Fig. 50 Open-circuit voltage of an HF ballast.

There are two ways of preheating:
- current preheating, with a more or less constant current through the cathodes in the HF-P
- voltage preheating, with a voltage depending on the actual working frequency (viz. dim level) for the HF-R where the cathode current is higher at lower dimming levels.

Due to this warm start, the lifetime of the lamps is not so much dependent upon the switching cycle as compared with the cold start method and conventional gear.

At the moment of ignition, the energy in the LC circuit is high enough to transfer the initial glow discharge into the stable burning discharge. After ignition the electronic ballast adopts its normal operating frequency.

No extra voltage is necessary for re-ignition at this working frequency, as the plasma in the discharge remains conductive at this high frequency.

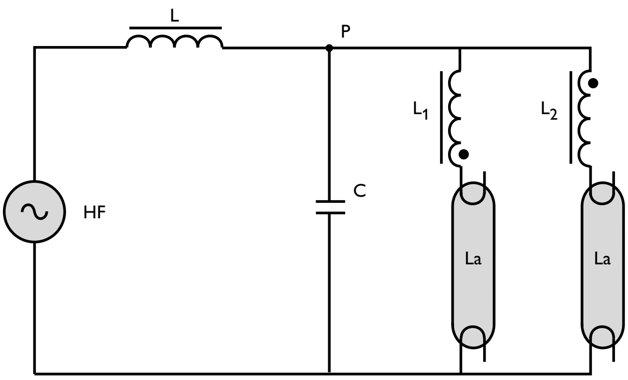


Fig. 51 Ignition with a twin-lamp HF ballast.

Ignition of a twin lamp ballast works on the same principle: in the preheat phase the voltage at point P (Fig. 51) is 300 V. In the ignition phase, this voltage will be 500 V, giving the required ignition voltage for both lamps. Once one lamp is ignited, the voltage at point P changes to 300 V, which is divided into 100 V for the lamp and 200 V for the transformer coil L1.

As transformer coil L2 is wound in the opposite direction, the open voltage for lamp 2 is still 300 + 200 = 500 V until the second lamp ignites as well.

The run-up time of fluorescent lamps is very short, as the lamps get their nominal lamp voltage almost immediately. But with the amalgam lamps (CFL, PL-T) it takes a few minutes before the amalgam is warmed up sufficiently to evaporate the amount of mercury necessary for the full light output. It can also take a few minutes for the lamp tube to reach its optimum temperature (see Section 3.6: Effects of temperature).

All HF ballasts have an automatic stop circuit. Should a lamp fail to ignite at the first attempt (for example at the end of its lifetime), the electronics switch off the ballast after about 5 s. In this way, the so-called anomalous condition that can be found with starter circuits is avoided, resulting in:
- after the switch-off, system losses of only 1 W
- no annoying flashes of the non-starting lamp or heating-up of the lamp caps
- no unnecessary radio interference.

After having replaced the lamp, most ballasts (exception: e-Kyoto) are immediately ready for operation again and the lamp starts without having to reset the mains (switching the mains supply off and on again). This means that lamp replacement can be done while the mains power remains on. Although not recommen-ded, this is often done in practice.

Should the lamp extinguish as a result of an interruption or dip in the mains voltage, instant re-ignition is guaranteed as soon as the voltage returns.

With the twin-lamp ballasts, the stop circuit switches off both lamps when one lamp fails or when either is not connected to the ballast. This is because the ballast control system is comparing both lamp currents and must them make them equal in stable operation. If one of the currents is zero after the ignition phase, the other will become zero as well.
Sometimes so-called 'independent lamp operation' is offered with twin-lamp ballasts. This feature suggests that if, in a twin-lamp system, one of the lamps should fail, the other one will continue to operate. However, with many such twin-ballasts this is only true as long as the system is not switched off. Once the mains is switched off, the intact lamp will fail to ignite at subsequent switch on. There are some special twin-ballasts available that do offer such independent operation, but these are also special as regards their (higher) price. In spite of this, this independent operation will be the trend for the future. The HF-P 418 TLD and HF-P 414 TL5 four-lamp ballast contains two parallel circuits of two lamps. Should one lamp fail, the other lamp of the same branch will be switched, but the second branch will continue to work. The HF-P 318 TLD and HF-P 314 TL5 three-lamp ballast is built up from one single-lamp circuit and a twin-lamp circuit. If the single lamp fails, the second branch is not affected. If one of the two lamps in the twin-lamp circuit fails, the single lamp is not affected.

4.1.5 Ballast types

The family of electronic ballasts can be divided up in various ways:
1. One, two, three or four-lamp versions
2. Fully electronic or with separate filter coil (old)
3. Integrated with lamp (CFL) or stand-alone
4. Standard or regulating (see Section 4.2)
5. Warm start (HF-P, HF-R) or cold start (HF-Basic, e-Matchbox, e-Kyoto).

The current Philips range consists of:
a) HF-Regulator with α-control for dimmable applications. The energy savings are maximised when dimmed; the lamps exhibit stable burning in every dimming position; and the lamp life is unaffected by dimming position.
b) HF-Performer with a smart-power IC, which keeps the lamp power constant over a wide range of mains voltages. The HF-Performer Ultra is a multi-wattage version (4 ballast types for 14 PL lamp types) for a wide voltage range (120-277V /50-60Hz). HF-Performer for TL5 lamps is equipped with an electrode-heating cut-off circuit, ensuring optimal lamp operation with respect to the lumen output curve of lamp and reduction in system energy losses.
c) HF-Basic for the most economical solution with all features for applications with infrequent switching.
d) e-Matchbox for minimal dimensions for 25 W maximum.
e) e-Kyoto as a low-specification solution for 1 and 2-lamp 'TL'D 36 or 58 W.

4.1.6 Cut-off principle

The cut-off principle minimises the current through the lamp electrodes shortly after the lamp is ignited. Not only does this save energy, it also lowers the temperature at the lamp ends. The standard TL-D lamp is optimised for a tube wall temperature of 40 ˚C, which is reached at an ambient temperature in the luminaire of 200 to 25 ˚C. The cold spot is in the middle of the lamp (see Fig. 52 and Section 3.6). The TL5, however, is developed to function in smaller luminaires at an higher wall temperature of 45 ˚C, which should be reached at an ambient temperature in the luminaire of 35 ˚C.
The cold spot is at one end of the lamp. Without cut-off (see Fig. 53), this cold spot would become too warm, meaning that the lamp would function optimally at an ambient temperature of 27 ˚C.
With cut-off (Fig. 53), the optimum is reached at an ambient temperature of 35 ˚C (see Fig. 54).

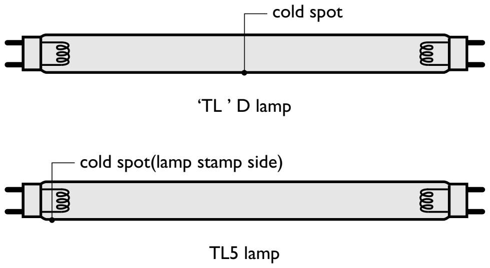


Fig. 52 Cold spot of 'TL'D and TL5 lamp.

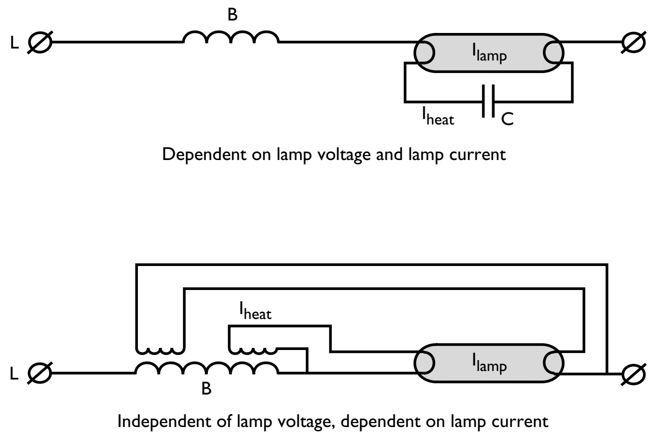


Fig. 53 Cut-off principle

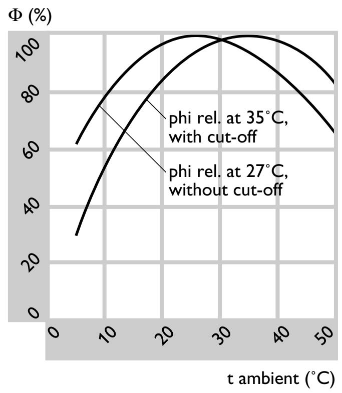


Fig. 54 Luminous flux with TL5 and HF-P ballast with and without cut-off.

4.1.7 Harmonic distortion

Due to the rectification that takes place and the presence of a buffer capacitor, the mains current is temporarily zero and has a peak waveform (see Fig. 55). According to Fourier's law, the peak waveform can be split up in the fundamental and its higher harmonic components.
The frequency spectrum can be measured by a spectrum analyser (see Fig. 56). Assuming the fundamental to be 100 per cent, the higher harmonics can be expressed as a percentage of the fundamental. International standards such as IEC 555-2 and EN 61000-3-2 restrict the amount of higher harmonics in the mains current for lamp circuits of more than 25 W.
For the example of the PL*E/C lamp the following results are obtained:

Harmonics		In,eff	In,eff/ I1,eff	IEC requirement
Number	Frequency (Hz)	(mA)	(%)	(%)
1	50	96	100	100
2	100	0	0	2
3	150	89	92	30 . λ
5	250	74	77	10
7	350	57	59	7
9	450	40	41	5
≥11	550	25	26	3

where λ = the power factor of the circuit.
Due to the circuitry, only the odd harmonics are present in the mains current.

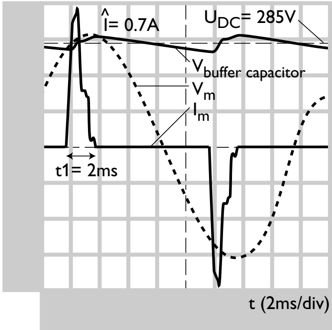


Fig. 55 Voltage and current shapes with a double-sided rectifier.

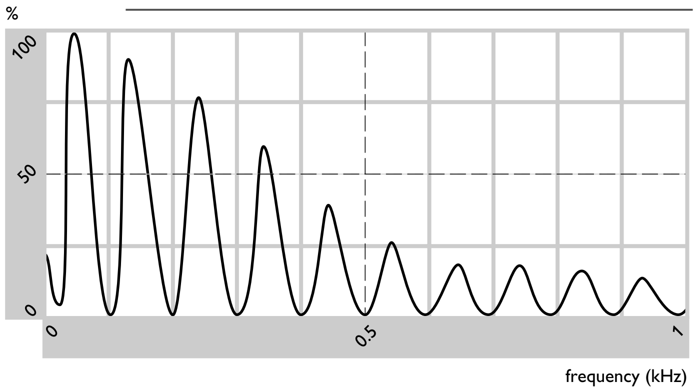


*Fig. 56 Frequency spectrum of the mains current for a PL*E/C lamp*

Comparing the results with the requirements, it can be seen that the limits are exceeded. This is due to the absence of the mains filter. For the PL*E/C lamp (and the e-Matchbox), this is acceptable, as the total system power is less than 25 W.

To adjust to the stated requirements for the maximum amount of higher harmonics, the circuit current has to be filtered. This can be achieved by a low-pass filter, which may consist either of a copper-iron coil or a fully electronic circuit.
All Philips HF ballasts (except for the PL*E/C and the e-Matchbox versions) have such a low-pass filter and are therefore designed in accordance with the regulations laid down in the IEC standards.

The electronic ballast system gives the following indicative values:

Harmonics	**$I_{n\ eff}$ / $I_{1\ eff}$ (%)**		
Number	HF-P 128 TLD	HF-P 258 TLD	HF-R 258 TLD
1	100	100	100
3	7	6.5	10
5	2.5	2	2
7	2	2	2
9	1.5	1.5	1
≥ 11	1.5	1	1
THD (%)	8	7.5	12

In this case the harmonics are well within the limits.

The term THD (Total Harmonic Distortion) is defined as:

$$THD = \sqrt{\sum_{n=2}^{\infty}\left(\frac{I_n}{I_1}\right)^2} = \sqrt{\frac{I_2^2+I_3^2+I_4^2+\dots}{I_1^2}}$$

which means the root mean square of the sum of all the higher harmonics divided by the fundamental. It can be calculated from the values obtained by the spectrum analyser, and for the PL*E/C lamp example this value is 1.44 (= 144 %). Nowadays, even with very simple hand-held instruments, this value can be measured very accurately.

For compliance with the standards the measurements of the higher harmonics are made with a supply voltage with a THD maximum of 2 %. In practice, however, the THD of the supply voltage can be much higher. According to the EN standard 50160 "Voltage characteristics of electricity supplied by public distribution systems" of November 1999 the maximum permitted THD for the supply voltage is 8 % for 95 % of the time with:

Odd harmonics				Even harmonics	
Not multiples of 3		Multiples of 3			
Order h	Relative voltage (%)	Order h	Relative voltage (%)	Order h	Relative voltage (%)
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.5	15	0.5	6-24	0.5
13	3	21	0.5		
17	2				
19-25	1.5				

This means that in practice the values for the harmonics in the supply current can be higher than the published values. The actual values then greatly depend on the harmonics present in the supply voltage. No problem should be expected when the THD of the supply voltage complies with the mentioned IEC 50160.

4.1.8 Power factor

In present-day publications the term power factor λ or P.F. is employed and 'cos φ' is no longer used.
The phase angle between the fundamental wave of the mains voltage and the fundamental of the mains current is called φ. This angle can be calculated or measured, and in the case of HF ballast circuits is nearly zero degrees (see Fig. 57), so extra compensation with compensating capacitors, as is the case in the conventional circuits, is not necessary.

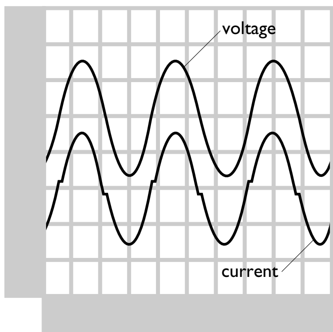


Fig. 57 The near-zero phase angle in an HF ballast circuit.

In practice, most supply voltage waveforms approach the sine wave shape rather well. In that case, the dissipated power is:

$P = U_{eff} \cdot I_{1,eff} \cdot \cos \varphi$

with $I_{1,eff}$ = the fundamental component of the mains current.

This means that the dissipated power is determined only by the fundamental of the mains current.
Higher harmonics of the mains current do not play a role for the lamp and ballast power, but they do contribute to the power losses in the cabling and thus influence the minimum diameter of the cable needed in the electrical installation.
If the mains voltage is not a pure sine wave, additional power will be dissipated in the lamp and the ballast.
In practice, the cosine of the angle φ is between 1 and 0.93 capacitive for HF lamp circuits.

The power factor of the circuit is the quotient of the actual consumed power and the product of the values of the mains voltage and mains current (r.m.s. values):

P.F. or λ = total wattage / mains voltage x mains current.

With RMS equipment these values can be measured very well.

The power factor is determined by:
- the phase angle φ
- the distortion of mains voltage and mains current.

If the mains voltage has a good sine wave (little or no distortion), the power factor will depend only on the harmonics in the mains current, according to the following formula:

$P.F. = \cos \varphi / \sqrt{[1 + THD^2]}$

where THD stands for Total Harmonic Distortion of the mains current (see former section).
This means that circuits having a different cos j can have the same power factor:
1. In a conventional circuit without parallel compensation the mains current is virtually sinusoidal (THD = 0.1), but the phase shift between mains voltage and mains current is about 60 electrical degrees (see Section 5.3.4), resulting in cos φ = 0.5 and a power factor of 0.5.
2. In the electronic PL*E/C circuit the phase shift is nearly zero (cos φ = 1), but there are a lot of harmonics in the mains current, giving a THD value of about 1.44 (or 144 per cent), which results in a power factor of 0.57.

The energy suppliers have to deliver to the circuit an apparent power of:

$S = V_{mains} \cdot I_{mains}$

but they only get paid for the average power
$P = \lambda \cdot V_{mains} \cdot I_{mains}$.

The electrical distribution system (cabling, transformers) must be capable of handling a current of I_{mains} instead of a current of I_{mains} . P.F.
This calls for thicker cabling and heavier transformers and introduces higher distribution losses. The supply authorities therefore demand compensation of the phase shift and limitation of the harmonic distortion by requiring a power factor of 0.85 or more for lamp circuit powers of 25 W and more. The power factor of H.F. ballasts is >0.95 , but leading.

4.1.9 Inrush current

The current that flows during the very first few milliseconds when switching on a luminaire or an entire lighting installation is called the inrush current.
This current is very important when making the right choice of switchgear and fusing, e.g. circuit breakers.
The inrush current is determined in part by the circuitry in use and in part by the properties of the mains supply, viz. the mains-supply impedance and the supply-cable resistance. The moment of switching in relation to the sine wave of the supply voltage also determines the value of the inrush current. The highest inrush current is when the ballast is connected to the mains at the peak of the mains voltage.

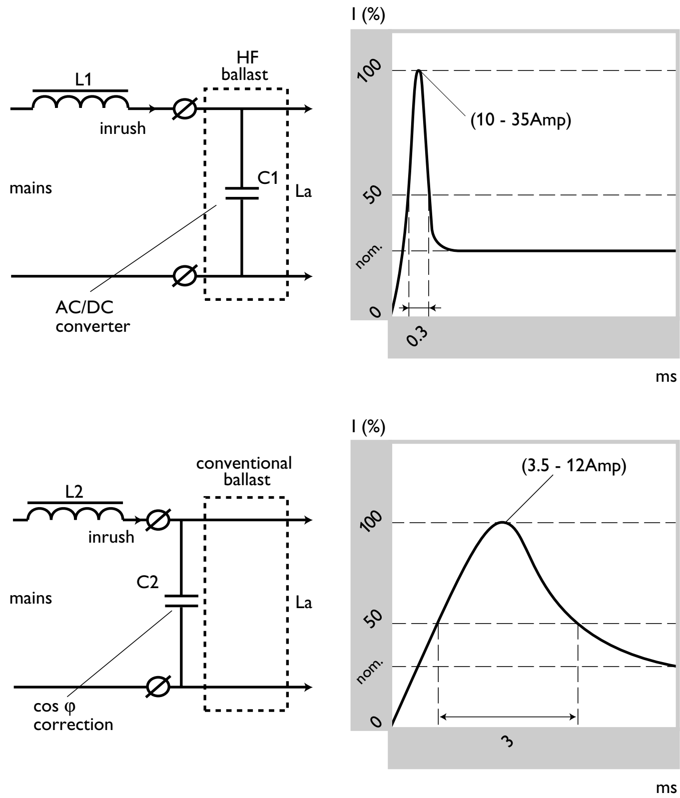


Fig. 58 The inrush current of an HF ballast compared with that of a conventional ballast.

With the introduction of HF ballast systems the effect of the inrush current became more important. There are two reasons for this:

1. Due to the electronics employed, more HF ballasts will switch on at the same instant, which adds to the value of the individual inrush currents to be supplied by the mains. Conventional ballasts switch on at random, avoiding this phenomenon.
2. For the same lamp wattage, the inrush-current pulse of an HF ballast is in principle higher and narrower than that of a conventional ballast (see Fig. 58). With an HF ballast, the inrush current loads the buffer capacitor C1, while in the conventional case the parallel compensating capacitor C2 is loaded.
   The value of C2 is lower than that of C1, which explains the trend of the currents. Compare, for example, the values for a 36 W 'TL'D lamp: conventional C2 = 3.6 μF, HF ballast C1 = 10 μF.

For the typical current/time curves of Fig. 58 we assume that the inductance of L1 equals that of L2. As a result, the I2t value of HF ballasts is higher than with conventional ballasts.

The inrush current can trigger Mains Circuit Breakers (MCBs), fuses or relays (as used in control systems) when the inrush currents peak in the hatched part of Fig. 59. According to the graphs, the maximum current of relay contacts is lower than that of MCBs (where the inrush current is sensed by a coil). When the coil of an MCB trips because the inrush current exceeds a maximum level, the main contacts (which are normally quite heavy, since they are so constructed as to be capable of switching off the current caused by short-circuiting) switch off, which explains the different behaviour with respect to normal relays.

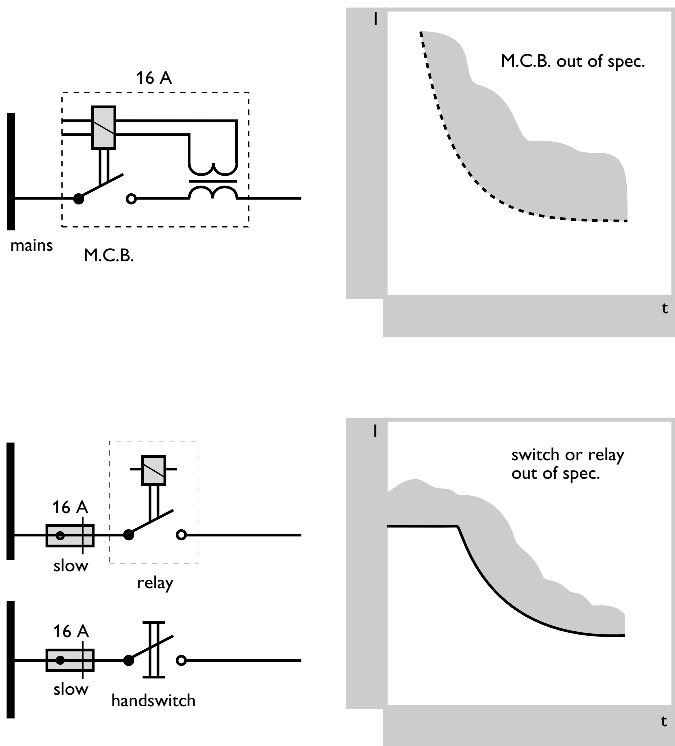


Fig. 59 Inrush currents may trigger MCBs, fuses or relays when they peak in the hatched part of the curves.

With the fully-electronic filter, the maximum inrush current is reached when the mains voltage is at its maximum value at the moment of switching on. The maximum value can be as much as 200 times the nominal mains current value, depending on the properties of the mains and RFI filter (see next section). Details for the various ballast types can be found in the product data sheets or can be provided on request.

4.1.10 Circuit breakers and fusing

The main purpose of protection devices such as mains or micro circuit breakers (MCBs) and fuses is to protect the cabling and the distribution part of the lighting installation from damage in the case of a failure or overload in the system. The rating of the protection devices is therefore primarily related to the cable core used in the installation, following the various national and international safety standards. In lighting installations, the commonly used MCBs and fuses have a rating of 10 A or 16 A. It will be evident that a 16 A device can handle a 1.6 higher load than can a 10 A device.

To prevent undesirable tripping of the MCB or the fuse from blowing, two criteria normally have to be taken into account:

- the maximum current during switching on or off in the part of the lighting installation that is protected by the MCB or fuse,
- the total nominal operating current during stable operation.

If the installation contains luminaires with electronic ballasts, the prime criterion for determining the maximum load for an MCB is the inrush current.
The switching characteristics of the various MCB types are laid down in recommendations such as CEE-19-2nd edition (see also Section 5.3.18).
An MCB consists of two over-current detectors, namely a temperature-dependent device (very slow) and a magnetic-current dependent device (very fast).
This magnetic part is sensitive to the inrush current.
The printed information on the MCB (e.g. B 16 A) gives the trip information for overload during longer times.
The published graphs for trip current and time are normally valid for waveforms from 50 to 200 Hz. But the frequency of the inrush currents is more than 1000 Hz, so the documentation of the MCB manufacturer is not enough to determine the maximum permitted number of HF ballasts. The exact numbers given in the datasheets are verified by actual measurements.
The different types of MCBs can handle different loads according to the table below:

Circuit breaker type	Relative number of ballasts compared with B - 16A (%)
B - 10 A	63
B - 16 A	100
C - 10 A	104
C - 16 A	170
L /I - 10 A	65
L/I - 16 A	108
G/U/II - 10 A	127
G/U/II - 16 A	212
K/III - 10 A	154
K/III - 16 A	254

The maximum number of ballasts that can be connected to an MCB thus depends on the MCB type and on the inrush current of the electronic ballast.
Details can be found on the ballast data sheets and can be provided on request by the local Philips Lighting organisation.

For example, on a C16A circuit breaker the maximum permitted number of ballasts type HF-P 258 TLD is 20. The mains current per ballast is only 0.48 A, so the MCB C16A is loaded with 9.6 A and about 2220 W.
However, the ½-value time of the total inrush current is about 520 A, measured with the typical mains impedance of 400 mΩ. This is equal to 15 m of 2.5 mm² cable and another 20 m to the middle of the power distribution under worst-case conditions. With a mains impedance of 800 mΩ the number of ballasts can be increased by 10 per cent.
Note that the maximum number of ballasts is given when these are all switched on at the same moment, e.g. by a wall switch.
The figures given for the maximum number of ballasts are for single-pole MCBs. For multi-pole MCBs it is advisable to reduce the numbers by 20 per cent.
If it is necessary to connect more than the allowed number of ballasts to one MCB, an inrush-current limiter is recommended (e.g. Busch-Jaeger type 6515). Alternatively, the TRIOS LRC1010 can be added (useful for max. 5 A load). So three TRIOS LRC1010s are needed for full loading of a 16A MCB. Another solution is to make use of the time delay of one or more AC relays (see Fig. 60). The natural activating time of approximately 10 ms (depends on relay type) ensures that the peak currents do not occur simultaneously.

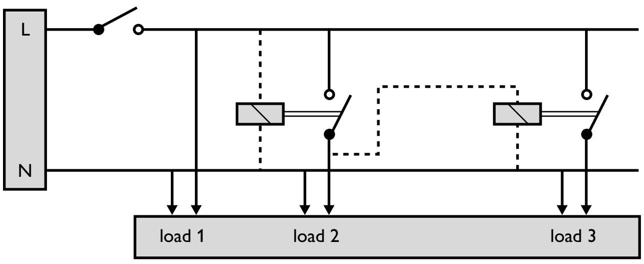


Fig. 60 The use of time relays to enlarge the capacity of an MCB.

4.1.11 Earth leakage

The use of a mains RFI filter causes a small leakage current through the neutral conductor of the mains supply (see Fig. 61). According to IEC 598, the maximum value of this leakage current should be 0.5 mA for Class 0 and II and 1 mA for Class I luminaires.
The operation of an installation containing a number of luminaires with electronic ballasts can become critical when this installation is connected to an earth-leakage switch. The total current passing through the neutral can reach a level that is too close to the tripping current of such a switch, also called Residual Current Detector (RCD) or Residual Current Circuit Breaker (RCCB).
In general, an RCD has a rating of 30 mA in which case the number of electronic ballasts is restricted to 30.

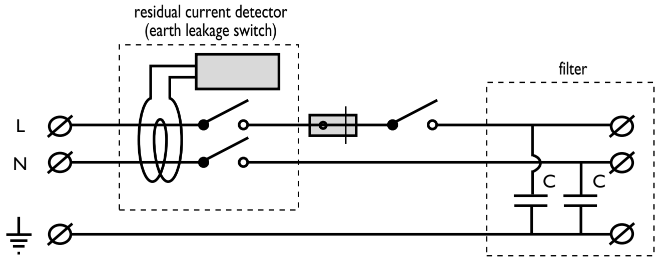


Fig. 61 The use of a mains filter to suppress mains-voltage disturbances, causing a small leakage current through the neutral conductor.

If it is desired to use more than 30 ballasts in combination with an RCD, this should be of a less sensitive type, having a higher trip current.
In all cases, and for a correct functioning of the RCD, the line and neutral conductors must be connected as indicated on the ballast and luminaire.
Practice has shown that the employment of so-called surge-proof short-time delay types is recommended, e.g. BBC types F360 S or F370.
Not all ballasts have an earth-leakage current.
Some ballasts having a plastics housing, for example, and so do not have a leakage current as they lack an earth connection.
When three or four HF-Performer ballasts are used in a Class I luminaire, the maximum earth-leakage current may surpass the maximum allowed of 1.0 mA.
Reversing the mains and neutral connections on one or two of the ballasts will cause the current to fall below the maximum of 1.0 mA.

4.1.12 Electrical connections

In order to guarantee the correct operation of a lamp/ballast system, the electrical connections to be made are marked with identifiable symbols. In some cases, colours are used to identify the correct connections. The wiring diagram has to be strictly followed, especially in HF systems. The wiring configuration can be rather complex, e.g. multiple lamps, multiple ballasts, emergency luminaire, master-slave, etc., so that a wrong connection may lead to failure to operate, malfunctioning, or even unsafe situations.
The data sheets of the ballasts specify the nominal mains current to be employed, but also give information about the minimum and maximum cross-sectional areas to be employed for the connectors. In most cases connectors are used to ensure easy insertion of solid wires. Also sometimes female connectors are used so that incorrect connection is not possible when proper polarity is necessary.

4.1.13 Internal and external cabling

Apart from what has been written in the safety standards for luminaires to guarantee a safe product (EN 60598 series), the cabling too may be of importance for the correct operation of the lamp/ballast system.
With respect to radio interference (EMC), some remarks are made in Section 2.3.4: Luminaire design. Some general information on electric wiring can also be found in Section 5.3.14: Electrical wiring.

The wires connected to the input side of the electronic ballast may not be bundled together with the wires connected to the output side.
When indicated in the ballast data sheet, also the maximum length and the capacity of the cables to the lamp should also be adhered to.
For economic reasons, it is sometimes desirable to operate two single-lamp luminaires from one two-lamp ballast (master-slave configuration, see Fig. 62).

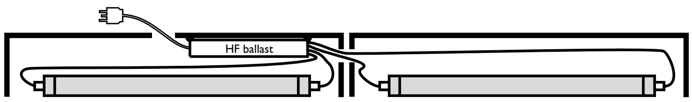


Fig. 62 Master-slave configuration with one ballast operating two luminaires.

Apart from the four cables for the lamp in the slave luminaire, a good metal-to-metal connection between the master and the slave luminaire is necessary. In order to maintain the benefits of the HF system with regard to ignition, radio interference and lumen output of both lamps, it is recommended that the distance 'D' of the cable length between the master and the slave luminaire not be exceeded (see accompanying table and Fig. 63).
At this spot the internal wiring becomes external over a certain length. The cable connecting the master luminaire with the slave luminaire should not be of the shielded type.

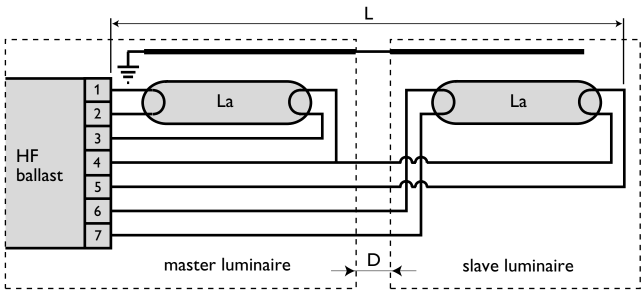


Fig. 63 Limited cable length between master and slave.

HF and master-slave wiring length (see Fig. 63)

Ballast type	D	L	Max.capacity between: Lamp wires	Lamp wires and earth
HF-B TLD	< 1 m	< 3 m	120 pF	120 pF
HF-P TLD	< 1 m	< 3 m	200 pF	200 pF
HF-P TL5	< 0.1 m	< 2 m	100 pF	200 pF
HF-R TLD/TL5	< 0.1 m	< 2 m	60 pF	150 pF

Light regulating ballasts are equipped with control wires. Due to the maximum current-carrying capacity of these wires of only 0.15 mA, the length and the diameter of the wires must be dimensioned so as to prevent a voltage drop of more than 0.5 V.

Due to the internal circuitry of the ballasts, some lamp connections are critical for the lamp performance and EMC behaviour. These so-called **hot points always must have the shortest lamp wires** and should be of equal length.

Also, in multi-lamp luminaires, the hot wires should be of equal length to avoid variation in lumen output between the lamps. The hot points are not marked on the ballast separately, but they can easily be found: on the ballast connection diagram the hot points are those terminals that have the shortest lamp wiring drawn. Correct wiring is essential for correct functioning.
Installation rules in most countries do not permit the routing of mains wiring and other wiring (e.g. control wiring, telecommunication wiring) together in the same cable ducts. The main reasons for this are the need to obtain optimum safety and to prevent disturbances and faulty connections.

4.1.14 Lifetime

The overall lifetime of an electronic ballast is determined by the lifetime of each individual component employed in the ballast and the effect of voltage, current and temperature occurring. The lifetime of an individual component is mainly dependent upon the quality of the material employed in manufacture and the manufacturing process. Usually, each component is checked not only for proper functioning immediately after manufacture, but also in use. Typical for electronic components is that if they have defects, these will show up in the early hours of operation. After this so-called burn-in period failures will only very seldom occur.
Philips electronic ballasts undergo a burn-in period for a specified period before leaving the factory. The purpose of this is to reduce the chances of early failures in an installation as much as possible.

In order to control the failure rate of a complete ballast, the method of calculating the Mean Time Between Failures (MTBF) is adopted. This takes into account the MTBF of all the individual components. The failure rate is 1 divided by the MTBF.
Since the maximum temperature within a luminaire is very important for the lifetime of a ballast, the calculations are normally based on a temperature of 65 °C at a defined spot on the ballast enclosure.
The quality of the design and of the components must result in a certain specified calculated failure rate.
For most electronic ballasts this is set to 1 per cent at 5000 hours.
According to the equation:

$R_t = e^{-\lambda t}$ or $\ln R_t = -\lambda t$

where R_t = remaining ballasts after the time t, and
λ = the failure rate 1 %/5000h = $0.20 . 10^{-5}$, it is found that 36.7 per cent of the ballasts are still operational after 500 000 h, or 50 per cent after 346 000 h.
The 10 per cent failure rate is reached after 52 680 h.
The temperature dependence of the failure rate can also be calculated. For most electronic ballasts this gives the following figures:

Test-point temperature (°C)	Failure rate (% per 1000h)		
	HF/B-P-R	e-Kyoto	e-Matchbox
55	0.15	0.20	0.30
65	0.20	0.28	0.40
75	0.30	0.43	0.60

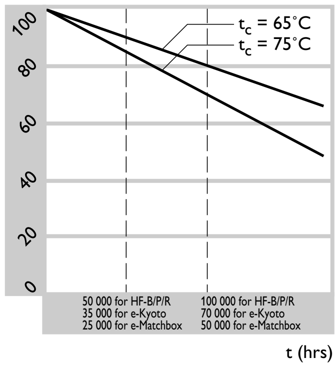


Fig. 64 Mean Time Between Failures (MTBF).

These calculated figures are verified by lifetime tests for the various ballasts (see Fig. 64).
One of the reasons for the increase in the failure rate at higher temperatures is the temperature dependency of capacitors employed, especially the electrolytic buffer capacitor.
In order to verify the outcome of calculations, lifetime tests are continuously carried out on batches of ballasts. It is found that during a long period after the burn-in period the lifetime of the ballasts is in accordance with the calculated failure rate. But after this long period, the failure rate then increases very rapidly, ultimately resulting in the end of the lifetime of the batch of ballasts (see Fig. 65). There are two major reasons for this phenomenon: drying up of the liquid of the electrolytic capacitors, and degradation of the soldered contacts.
The soldered contacts are specified to have a lifetime of 2500 to 3000 switches in the temperature-change test of -20 ° to +100 °C. This wide temperature range of 120 degrees will not be found in practice; temperatures between + 20 ° and + 60 °C (a range of 40 degrees) are more likely.

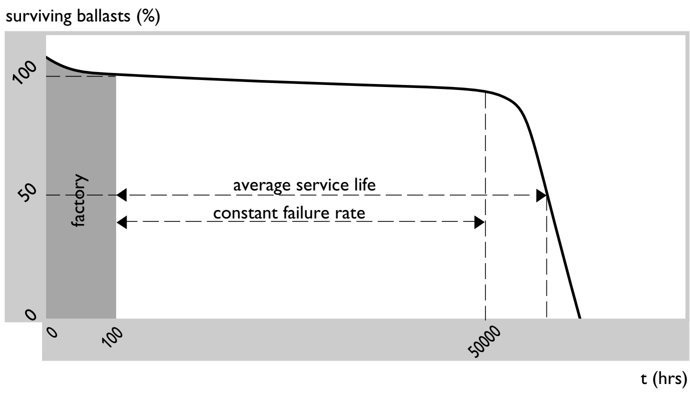


Fig. 65 Lifetime curve of electronic ballasts, showing rapidly increasing failure rate after a certain period.

The actual switching lifetime can be calculated from the following equation:

N_{switch} = 2500 x (120 / practical temperature range)^2.

So in the example:
N = 2500 x (120/40)^2 = 2500 . 9 = 22 500 times.

Supposing the average burning time of the fluorescent lamps is 2 hours, this would result in a lifetime of the complete ballast of 2 x 22500 = 45 000 hours.

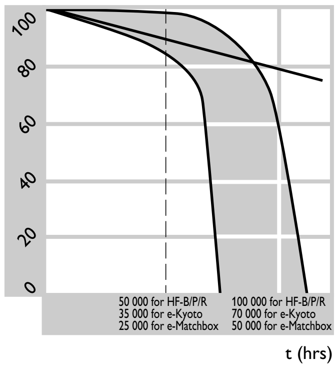


Fig. 66 Total of failure mechanisms.

The time after which 50 per cent of the ballasts have failed is called the average service lifetime. For most ballasts in normal operation, this average lifetime is approximately 50 000 h at a fixed specified case temperature (65 °C). A temperature increase of 10 degrees halves this average service lifetime (thus, 75 °C gives 25 000 h), while 10 degrees lower doubles this figure (55 °C gives 100 000 h). Taking into account the various tolerances and spreading results in Fig. 66.

4.1.15 Effects of mains voltage fluctuations

The mains voltage to which a luminaire is connected is never constant; it is influenced, for example, by the switching on and off of other loads. Therefore, the voltage level can only be guaranteed between minimum and maximum tolerances.
Moreover, the nominal voltage can differ from country to country. In the UK, for example, the nominal voltage is 240 V compared with 230 V for the rest of Western Europe.
The nominal operating voltage of a ballast can be found in the product data sheets. It may be a fixed value, as is the case with conventional ballasts.
The present range of Philips HF ballasts is suitable for voltages between 220 V and 240 V 50/60Hz.

With respect to voltage fluctuations, there are two requirements:
1. A general safety requirement. No unsafe situation should occur within the range V nominal ± 10 % (in this regard attention should, for example, be paid to lifetime, temperatures, voltages).
2. A performance requirement. The circuit must perform within specified limits within the range V nominal - 8 % to + 6 % (in this regard attention should, for example, be paid to lumen output, currents, (re-) ignition).

And, again with respect to voltage fluctuations, the electronic ballasts can be divided in two groups:
1. A group in which the circuit power, lumen output, lamp current, etc. vary noticeably with fluctuations in the mains voltage (see Fig. 67). Examples are the old types BHF, BPL and the new types e-Matchbox and e-Kyoto.

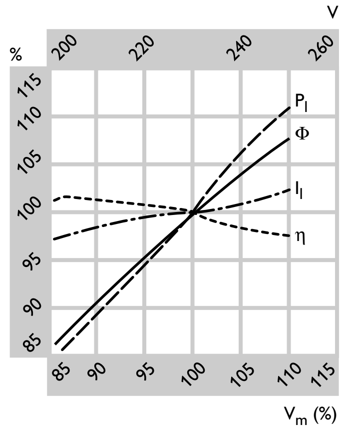


*Fig. 67 Considerable influence of mains-voltage fluctuations on lamp power (Pl), luminous flux (Φ), efficacy (η) and lamp current (Il) with PL*E ballast.*

2. A group based on the independent mains principle, where the lamp power and lumen output hardly change with variations in the mains voltage (see Fig. 68). Examples are the present ballasts HF-P, HF-B and HF-R.

It must be kept in mind that with the independent mains principle (sometimes also called constant-wattage) the mains current will rise with decrease in mains voltage.

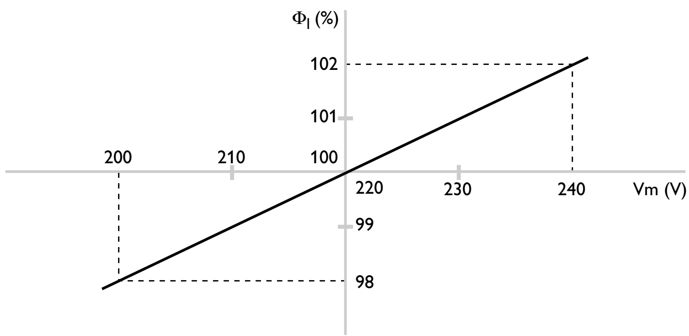


Fig. 68 Constant-wattage ballasts (e.g. HF-R). For a given mains voltage variation between 200 V and 240 V, the light output remains constant (tolerance ± 2 %).

All ballasts can withstand a certain over-voltage for a specified time, for example 380 V for 5 minutes. See for this point the product data sheets.

Moreover, some electronic ballasts have an over-voltage detection. When the mains voltage rises above a certain value (usually 280 V r.m.s.), perhaps, due to a fault in the installation or a mistake in a testing procedure, the lamps are switched off. This switch-off feature provides a clear indication that the installation is not functioning properly and that corrective action is necessary. The lamps remain off until the unduly high mains voltage is corrected and the ballast is reset. Resetting must be done by switching off the mains supply to the ballast. After the ballast has switched off the lamps (in case of over-voltage), the high mains voltage is still connected to the input circuit. It is therefore essential that corrective action be taken immediately.

Additional information can be found in the specific product data sheets.

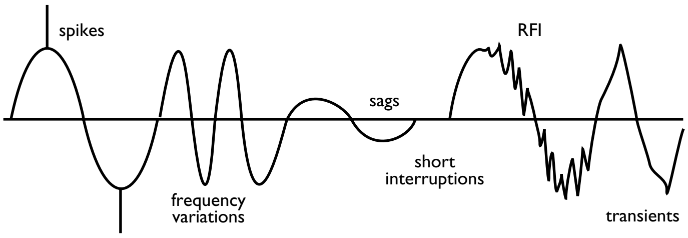


Fig. 69 Different types of mains-voltage disturbances.

Transients and dips

The mains supply voltage can be disturbed in many ways, see Figs 69 and 70.
Disturbances of short duration, especially, can cause an interruption of the light output. Example, quoted from IEC 1000-2-2:5:
'At present as an approximate guide, it can be stated that an individual consumer in a town may suffer on average one to four times a month from voltage dips which exceed 10 % of the nominal supply voltage and which are due to causes outside his premises. The duration of these voltage dips is usually between 60 ms and 3 s, but durations of around 10 ms are possible mainly when faults are eliminated by fuses.'
In rural areas, generally supplied by overhead lines, the voltage dips are much more frequent, but no useful estimates of the rates of occurrence of such dips are available.

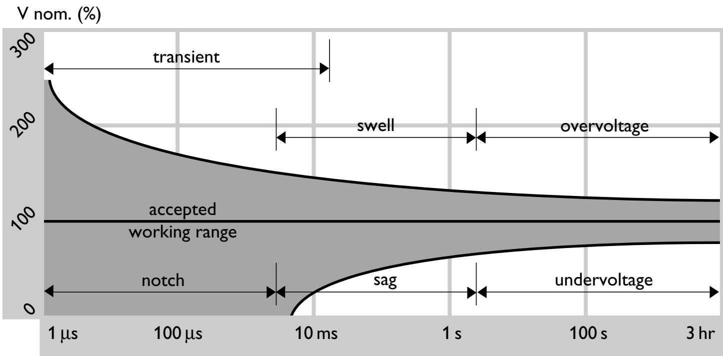


Fig. 70 Effects and duration of mains-voltage deviations.

Peaks or transients can also damage the electronic ballast. There are several old, new or revised recommendations and standards covering this subject. To comply with the latest norms, Philips ballasts are, or will be, designed according to the latest norm IEC 1547 (draft): Equipment for general lighting purposes - EMC immunity requirements.
This ensures a very good immunity to the most common mains-supply distortions.

4.1.16 Ambient and operating temperatures

The temperature dependence of the various lamps has been described in Section 3.6. The behaviour of the total lighting system (viz. lamp, ballast, luminaire, wiring, mounting and supply voltage) with change in temperature is mainly based on the temperature of the lamp in the actual situation.

In general, the specifications of electrical components are not valid under -15 ˚C/ -25 ˚C, so below these temperatures there is no guarantee for proper functioning of the ballasts.

The ambient temperature range for the HF ballasts in the compact PL*E lamps is from -20 ˚ to +55 ˚C. Mounted in a luminaire, the hottest spot should be below 100 ˚C (see Section 3.6 and relevant product information).
The ambient temperature range of 'TL' and PL-L HF ballasts is indicated on the ballast with the letter ta and ranges from -15 ˚/200 to + 50 ˚/70 ˚C. Due to the low watt losses in the HF ballasts, the temperature rise Δt of the ballast itself is limited to a maximum of approximately 15 degrees. Exceptions are, however, possible.

An electronic ballast is usually built into a luminaire, so the ambient temperature around the ballast cannot be predicted exactly. A test point, tc , is therefore defined on the outside of the ballast enclosure, for which a maximum permitted temperature is specified for.
This is normally 75 ˚C. The test point will reach this temperature when the ambient temperature around the ballast is 50 ˚-60 ˚C, depending on the type of ballast.
As long as the temperature of the test point remains below the specified maximum, the components will not be subjected to temperature overload.

The t_c value is built up as follows:
Room temperature (e.g. 25 ˚C) plus temperature rise in the luminaire (e.g. 25 ˚C) equals ambient temperature for the ballast (50 ˚C in this case). Ambient temperature plus temperature rise of the ballast itself (e.g. 15 ˚C) gives t_c = 50 ˚ + 15 ˚ = 65 ˚C.
From this it follows that the room temperature directly influences the test-point temperature. The temperature rise of the air in the luminaire has to be measured.
Variations of 15 ˚C between a completely closed plastics luminaire and an open (bare lamp) metal luminaire are possible.
Also, the distance from the ceiling influences the cooling properties of a luminaire, for example:

Distance to ceiling (cm)	0	1.25	2.5	5	10	15
Temperature drop (K)	0	1.5	6	14	20	22.5

As the enclosures of the electronic devices are often made of thin metal or some type of plastics, the measurement of the temperature at the test point must be done very carefully. The use of a rather large test finger, as supplied with some multimeters, will undoubtedly indicate temperatures that are too low.
Measurements must be made by means of thermocouples, which must be firmly glued to the surface (and not, for instance, with adhesive tape).

The most common application of fluorescent ballasts is in indoor installations. When employed in outdoor installations, the luminaire must be of the closed type, minimum classification IP54. In cold situations, especially, striation may occur.
In order to avoid the negative influence of humidity on ballast components and metal connections, special lacquered ballasts are available.

4.1.17 Earthing

According to the basic wiring diagrams there are two points that should be connected to earth:
the ballast enclosure and a 'strip' along the lamp.

1. The ballast enclosure

The ballast enclosure has to be connected to earth potential with a view to safety aspects. Due to the high operating frequency and the high starting voltage, the metal housing can get statically loaded. The static charge is in itself not dangerous, but contact with the charged metal of the housing (for example while carrying out lamp replacement) can cause an unpleasant jolt to the senses, with possibly undesirable consequences.
The second reason for earthing the ballast housing is to fulfil the RFI recommendations. A part of the mains voltage is connected to the ballast housing through a capacitor of the RFI filter (see Fig. 71). The RFI filter also has the function of protecting the components of the electronic ballast from, amongst other things, transients (voltage peaks) in the mains voltage. Earthing is therefore essential.
The final reason for earthing the ballast enclosure is to obtain optimum safety at the end of the lifetime of the ballast.

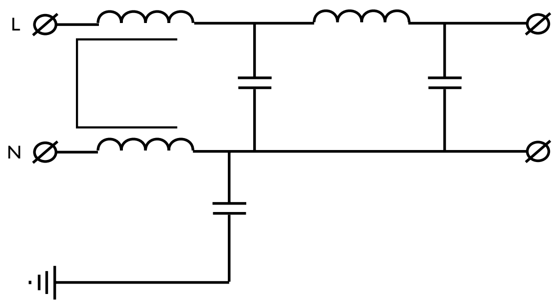


Fig. 71 Part of the mains voltage is connected to the ballast housing via a capacitor of the RFI filter.

Earthing of the HF ballast is effected via the fixing screws to the grounded mounting plate. Tooth-lock washers should be used to ensure a good earth contact through the paint or lacquer.

2. A 'strip' along the lamp

To ensure reliable ignition, especially at low temperatures, and proper operation, especially with the dimming ballasts, the lamps should be mounted at a certain maximum distance from an earthed surface: 20 mm with normal 'TL'D lamps, 6 mm with 'TL'5 lamps and 12 mm for PL-L lamps. In the case of a metal luminaire, the earthed luminaire itself can serve this purpose. In the case of a plastics luminaire, an additional metal strip with a width of at least 1.5 times the lamp diameter covering the entire length of the lamp, has to be incorporated.

In most applications the luminaires are of the electrical safety class I variety, meaning they are provided with an earth point (see Section 2.2). In that case there are no problems.

Although not yet laid down internationally, the Philips philosophy is not to use class 0 luminaires in combination with HF ballasts.
When HF ballasts are built into class II luminaires, there are two possibilities:

1. There is no earth terminal or earth connection.
   In this case, connect the ballast housing (see point 1) to the metal ignition strip (see point 2).

2. There is an earth contact, for the starting aid only, but it is not connected to exposed metal parts. In this case, do not earth the ballast housing.

To test the earthing and the electrical strength there are two tests:

1. Testing the electrical strength of the ballast:
   Connect all ballast inputs and outputs together and connect 1500 V AC for 1 minute between this point and earth (=ballast housing).

2. Testing the insulation of the wiring:
   Connect 500 V DC (megger) between earth and (one by one) the supply cables phase and neutral.

These tests can be done without any danger for the electronic ballasts. But keep in mind that in the low-pass filter, capacitors are connected between phase/neutral and the earth point. This means that in the tests a small current will flow (see also Fig. 71 and Section 4.1.2).
These tests must not be carried out on the dimming inputs '+' and '-' of dimming ballasts, as such ballasts will be harmed.

4.1.18 Fault finding

Often when a luminaire becomes inoperative, the cause is not attributable to the ballast. It is therefore important to examine all its components before removing the ballast for replacement. The following procedure is recommended:

1. First check that lamp type, ballast type and nominal mains voltage are in accordance with the ballast marking.
   Then check the lamp-burning position.
   Finally, look for evidence of moisture or excessive heat.

2. Check the lamps and replace in case of:
   - Blackening of the lamp ends,
   - Broken lamp pins,
   - Damaged lamp electrodes - these can be measured with a standard ohmmeter: the resistance between the two lamp pins at one lamp cap should be between 1 and 50 Ω, depending on the lamp type.

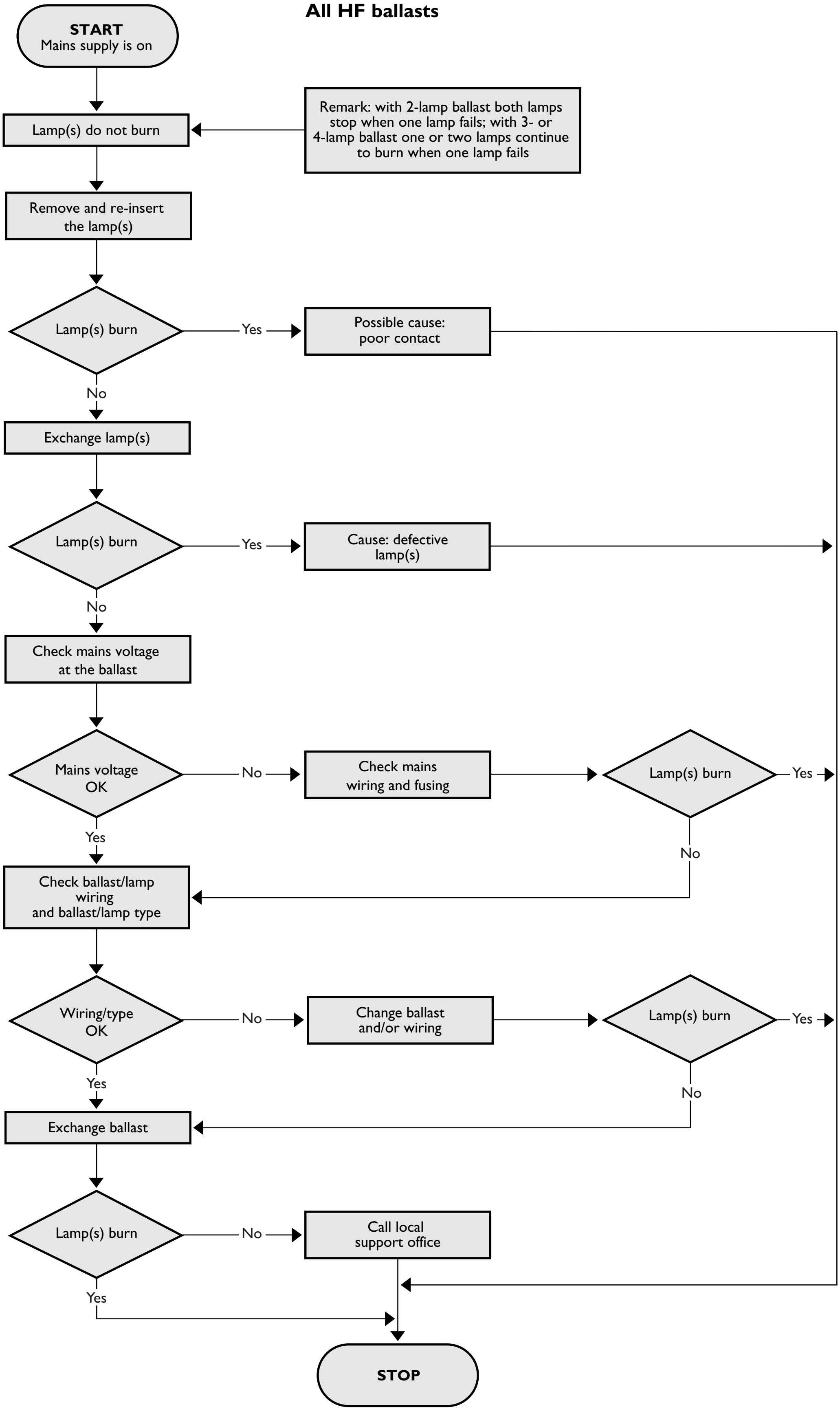
3. Examine all lamp sockets for proper and positive contact with the lamp pins. Possible defects:
   - Improper seating of the lamp within the socket,
   - Too great a socket spacing,
   - Broken sockets.

4. Examine all connections within the luminaire for conformance with the wiring instructions appearing on the ballast. With the twin-lamp version in particular, wiring faults can easily occur. Check that the wires are properly stripped and that they are in accordance with the specifications laid down in the ballast documentation so that they make contact in the insert connector.

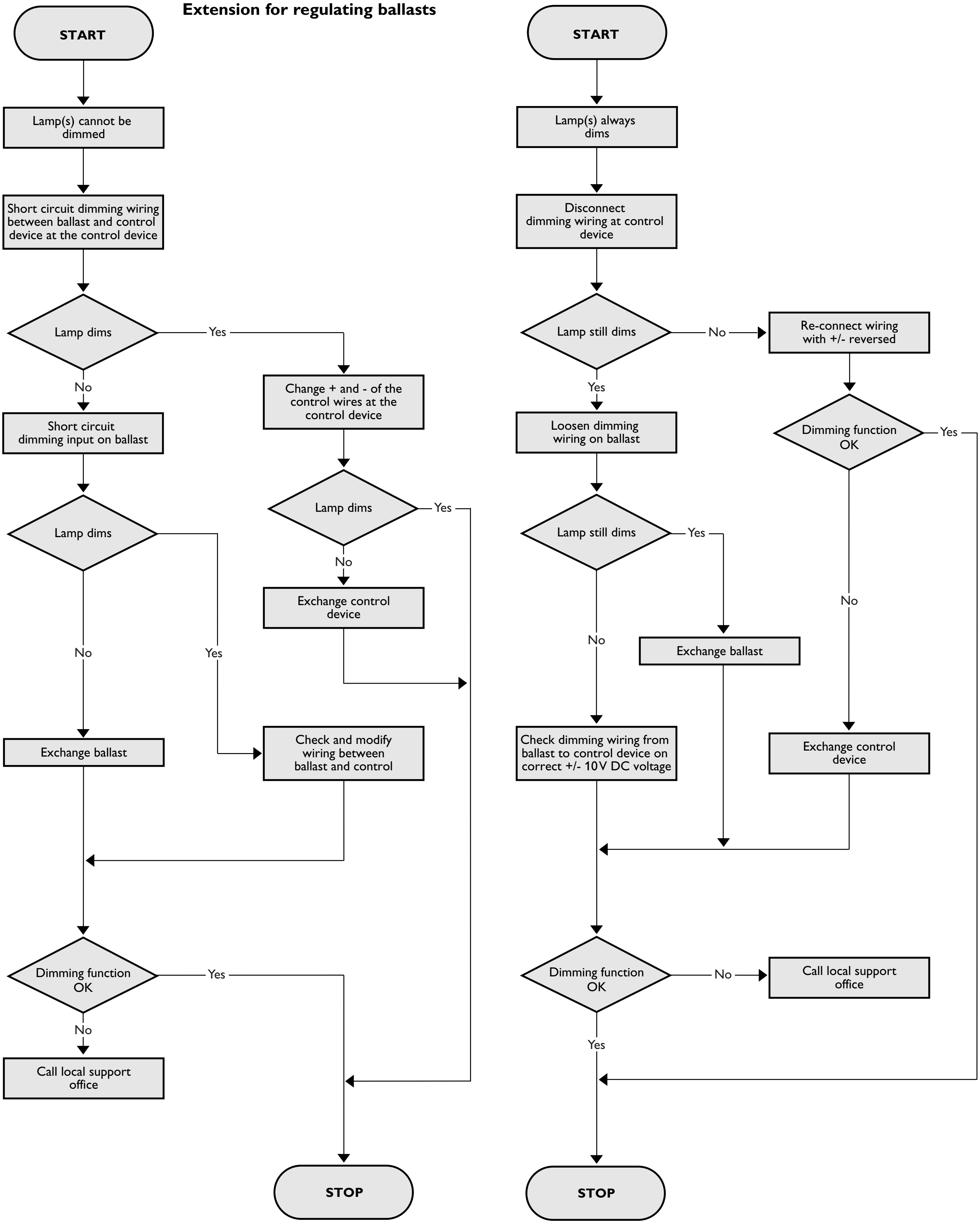
5. Check the supply terminals and the earthing:
   - Phase and neutral must be connected in the proper way,
   - The ballast housing and starting strip must be connected to the earth terminal,
   - The luminaire must be connected to the earth terminal,
   - Check the mains fuse (slow-acting type) or MCB,
   - Check the mains supply for voltage and frequency.

When, in a multi-lamp luminaire, one lamp is switched off, the other lamp(s) may be switched off too (see Section 4.1.4). It is advisable to replace all the lamps at the same time in a multi-lamp luminaire.
The HF ballast cannot be repaired. And in the interests of safety it should not be opened. If, after observing the test procedure described above, the luminaire is still not functioning properly, the ballast will have to be replaced.
Due to the high operating frequency and high starting currents, it is not possible to make electrical measurements at the lamp side of the ballast with a normal multi-meter.
Philips HF ballasts are equipped with a fuse at the input. This fuse protects the power supply from a possible short-circuit in the ballast and the ballast itself from over heating. A blown fuse invariably indicates a defect in the ballast. There is therefore no reason and no possibility to replace this fuse. If it blows, the whole HF ballast will have to be replaced.
Flow-charts for trouble-shooting are given below.

All HF ballasts



Extension for regulating ballasts



4.1.19 Installation aspects

Lamp wiring for 'TL'5 and PL-T circuits in luminaires

Introduction
Historically, lamp voltages (under normal conditions) for 'TL'D, PL-L and PL-C lamps have always been below 200 V. Lamp components and lamp wiring could have the same voltage rating as normal mains voltage (< 250 V). New, more efficient types of lamp such as 'TL'5 and PL-T have lower lamp currents, but higher lamp voltages. As a result, the 250 V rating for lamp wiring and components is sometimes inadequate. The impact of the step from 250 V-rated components/wiring to higher voltage-rated (e.g. 500 V) components/wiring is described below.

European harmonised wires

The European harmonized wiring is specified in the Cenelec standard (HD 21.3.S2).
Commonly used wires are classified as H05 or H07, which means:
H05: voltages up to 300V(330V*) rms; core cross-section 0.5 mm² ... 1.0 mm².
H07: voltages up to 450V(495V*) rms; core cross-section 1.5 mm² ... 400 mm².
* Maximum permissible permanent voltages are 10 per cent above nominal value

'TL'5 and PL-T lamp voltages

1. Non-dimming systems
   For all existing 'TL'5 and PL-T lamps the maximum voltages from any lamp wire to earth do not exceed 250 Vrms. Therefore H05 classified wiring can be used.

2. Dimming systems**
   With the following PL-T and 'TL'5 lamps the maximum wire-to-earth voltages exceed the maximum voltage of H05 classified wires.
   1. PL-T systems: 32 W & 42 W
   2. 'TL'5 HE systems: 28 W & 35 W
   3. 'TL'5 HO systems: 49 W & 54 W
   Depending on lamp type, the maximum voltages can increase up to 430 Vrms.
   Therefore the use of H07 (450 Vrms) wiring is necessary.
   HF-Regulator ballasts can handle a conductor cross-section of 1.5mm², but lampholders or other components are often not suitable for handling a cross-section larger than 1.0 mm². Using special wiring (not harmonised) rated at 450Vrms. with a conductor thickness of 0.5-1.0 mm² can be the solution, but since this is not a standard wire, it may be difficult to obtain. Cable suppliers/manufacturers have to be consulted.

** Lamp to earth voltages higher then 330 V only occur at lower temperatures (< 20 °C) and at lower dimming levels (< 40 %).

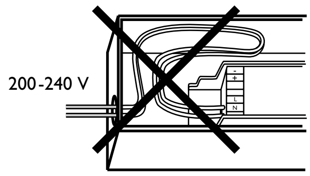
Note the following:
- The live and neutral terminals of the mains must be connected to the correct terminals of the ballast. Both connections are important because ballast and lamp construction relies on this convention for maximum creepage path and correct ignition.

- Crossed-over phase and neutral terminals can cause increased radio interference, higher earth leakage currents and/or ignition problems.
- It is recommended that the bottom plate of the ballast, the starting-aid strip and the luminaire be connected to earth. The electronic ballasts must be well earthed in the luminaire. This can be done via the fixing screw to the grounded mounting plate. Tooth-lock washers should be used to ensure a good earth contact through the paint or lacquer of the ballast bottom plate.
- HF ballasts are short-circuit proof: a short-circuit on the secondary side (lamp side) will not damage the ballast. The internal fuse will not 'blow' in the case of short-circuits in the luminaire wiring.
- The lamps should be mounted at a maximum distance of 20 mm from a metal surface. In the case of a metal luminaire, the earthed luminaire itself can serve this purpose. In the case of a plastics luminaire, an additional metal strip, well connected to the housing of the ballast and covering the entire length of the lamps, has to be incorporated. The metal strip must be approximately 30 mm wide. The ignition aid helps to ignite the lamps, especially at colder temperatures.

- For master-slave arrangements, see Section 4.1.13.

Lamp performance and radio-frequency interference
- The following advice is important for achieving optimum lamp performance and to reduce radio-frequency signals:
- Keep wires as short as possible,
- Never bring together mains and lamp wiring (spacing > 1 cm),
- Do not fix lamp wires tight to earthed surfaces,
- Use loose wires for lamp wiring. If bandcable is used, ensure that cable length is as short as possible,
- Ensure that the length of the wires is in accordance with the advice given for each ballast type,
- Use 4 mm diameter screws to mount the ballast in the luminaire,
- Avoid loops in the wiring.

General advice
- The mounting position of the ballast can influence the lamp temperature and thus the light output.
- In two- or three-phase networks with a neutral conductor, this neutral must have the same cross-section as the phases.
- Use stranded wire in places that are subjected to vibrations or where the wire must be able to bend in use.
- Most ballasts and lampholders are equipped with either single or double-insert contacts, suited for solid core wire of 0.5 -1.0 mm^2 (maximum diameter of insulation 2.6 mm), which should be stripped over a specified length.
- At ambient temperatures below 100C, closed luminaires should be used to avoid reducing the lighting levels.
- Most electrical energy in a lighting system is transformed into heat. Saving 4 watt (lighting) input power will save approximately 1 watt on the air-conditioning system when in use - and cooling costs are three times higher than heating costs!
- 'Hot' terminals (see Section 4.1.13) must have the shortest lamp wires. In multi-lamp luminaires this hot wiring must be of equal length for each lamp (see Fig. 72).



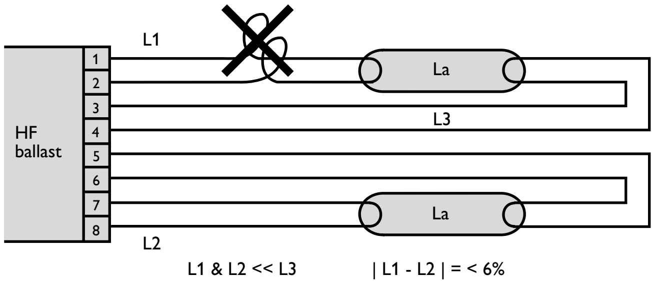


Fig. 72 Make wiring as short as possible.

- In some ballast documentation, restrictions are mentioned for the maximum capacity between the output terminals and between output terminals and the ballast housing (viz. earth).
  There are three reasons for this:
  1. These capacitances influence the ignition characteristics, especially in conditions of extreme cold.
  2. These capacitances influence the degree of EMC.
  3. With regulating ballasts at low settings, the performance will be out of specification when the capacitances are too large. The light output can drop below the specified minimum, unstable burning may take place and/or differences in light output between the various lamps can occur.

The capacitances, which in practice depend on the length and the sort of lamp wires and the way they are attached, should therefore be kept to a minimum.
It is recommended that the lamp connections be made with separate wires and not with flat cable or 4-core cables. Screened cables should also be avoided.
Commonly-used single-installation wire of 0.5 to 1 mm^2 has an average capacitance of 30-80 pF/m, while mains cable of 3x1.5 mm^2 has a value of 120 pF/m.
For a ballast mounted directly on an earthed mounting plate or metal luminaire housing, these figures can be a factor 2.5 higher. Mounted on spacers providing a 3 mm distance to the earth, they can be approximately a factor 1.8 higher. In normal practice, the values for a 2 x `TL`D 58 W luminaire, constructed according to the basic rules as stated in Section 2.3.4, will be between 35 and 60 pF/m. To verify the capacitances in a luminaire, they have to be measured with special capacitance-measuring equipment, at a testing frequency of 1 kHz or more.

- High-voltage test:
  All primary connections must be short-circuited before carrying out a high-voltage test. To avoid voltage surges, the test voltage should only be applied after the connections to the test instruments have been made. Initially, no more than half the prescribed voltage should be applied before raising it gradually to the full value. Test voltage maximum: 2U + 1000 V AC, 50/60 Hz for maximum of 1 minute between short-circuit and housing.

For the HFR ballasts:
1. Short circuit the '+' and '–' of the dim input with the L & N at the mains input and apply the High Voltage from these to earth
2. Short circuit the '+' and '–' of the dim input with the earth and apply the High Voltage from these to the short-circuit L & N.

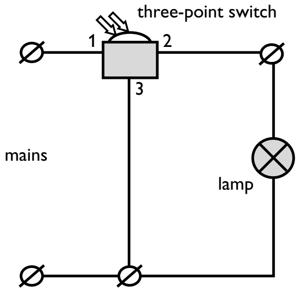


*Fig. 73 Three-point switch suited for PL*Electronic lamp.*

- Insulation resistance test:
  When the insulation of the wiring in an installation is tested by meggering, voltages of maximum 500 V DC with limited currents (< 2 mA) between line and earth or neutral and earth are followed. After testing, ensure that the neutral is reconnected.
- PL*E lamps can be used in circuits having dusk switches or movement detectors if the circuit has a 3-point switch. In this type of circuit the supply voltage for the switch is independent of the lamp current (Fig. 73). Problems such as flickering and premature failure may arise if the lamp is used in circuits having a 2-point switch (Fig. 74).

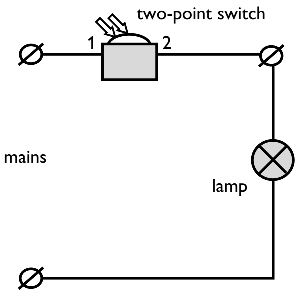


*Fig. 74 Two-point switch not suited for PL*Electronic lamp.*

- Interference with infrared
  Video/audio apparatus, computers and lighting installations are increasingly being operated with infrared remote control. The infrared signals of these devices have a frequency of about 36 kHz. To avoid interference with this kind of equipment, the working frequency of HF electronic ballasts is chosen accordingly. Interference can only be expected when the distance between the lamp and the infrared receiver is small and the lamp shines directly into the receiver.
  The frequencies of interpreter/congress systems are 55 kHz, 95 kHz, 135 kHz, 175 kHz, 215 kHz, 255 kHz, 295 kHz, 335 kHz and 375 kHz.
  1. It is not advisable to use HF regulating ballasts in the vicinity of the above-mentioned interpreter systems. When the ballasts are regulated, the frequency signals might interfere with such a system.
  2. Use only HF electronic ballasts working on a frequency range below 30 kHz.
  3. Do not use the lower frequency bands between 55 kHz and 175 kHz of the interpreter system.

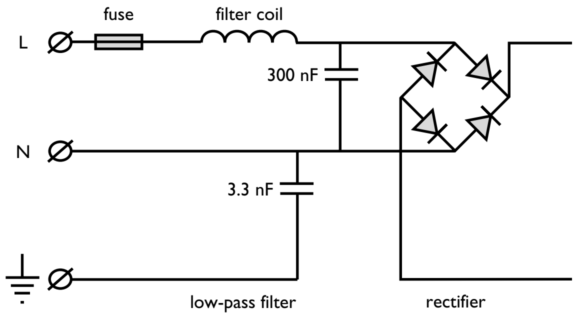


Fig. 75 The low-pass filter.

- Electric shocks with luminaires with HF-P ballasts and without Earth.
  In the HF-P ballasts, a low-pass filter is connected between Phase, Neutral and Earth (see Fig.75). This is to suppress the Radio Frequency Interference (RFI)-level to comply with European norms such as EN 55015.
  In most cases, the ballast housing is connected to earth via the luminaire. When the circuit is connected completely and correctly, there will be scarcely any current through the small 3.3 nF capacitor. However, when Phase and Neutral are interchanged, there will be a small current of no more than 0.5 mA, flowing from Phase via 3.3 nF to Earth.
  As long as the ballast is connected to the earth, nothing will happen and a normal earth-leakage switch will not function (as long as there are not too many ballasts involved).

However, if the earth is not connected and the Phase and Neutral are interchanged, then the ballast housing and the luminaire is connected to the Phase via the capacitor 3.3 nF. A well-earthed person can then feel an electric shock when touching the metal luminaire.
In principle, this shock is harmless, because the maximum current via the capacitor and the person is only 0.5 mA, which is well below the danger limit. However, as a result of panic reactions, secondary effects can result in harmful situations.

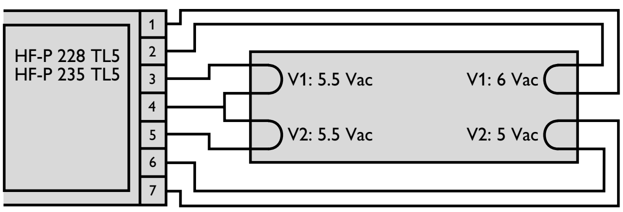


Fig. 76 Correct ballast-lamp connections.

- During manufacture of the luminaire, mistakes can be made when inserting the wires in the lamp connector of 2-lamps ballasts. The lamp seems to function normally, but after 700 to 1000 h, early failures and early blackening of one lamp end do occur.
  Example correct connections: Fig. 76

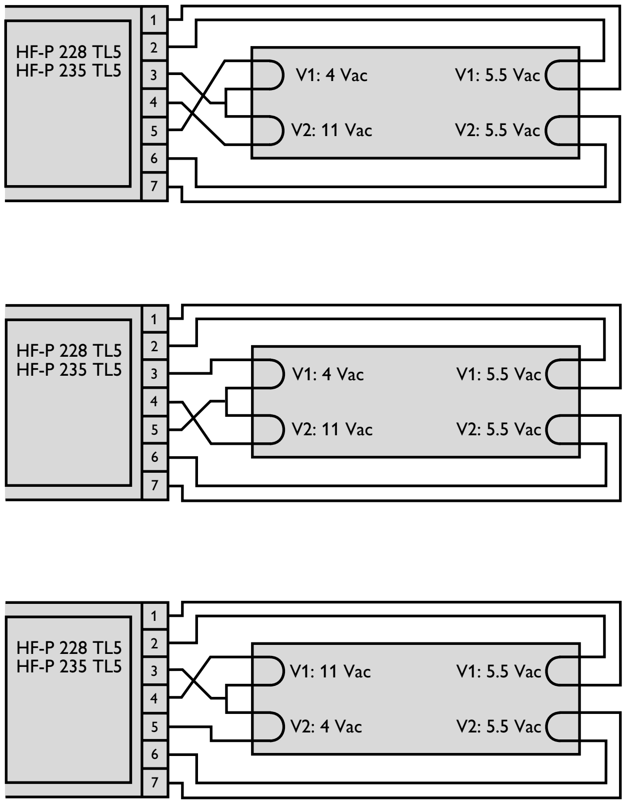


Fig. 77 Incorrect ballast-lamp connections.

Possible faulty connections, Fig. 77

During starting, the "high voltage" lamp electrode is clearly lighted up for approximately 1 second before the lamp ignites.
The measured electrode voltages will vary, according to when measurements are taken and the tolerances and types of ballasts and lamps involved.
A mistake in the wiring has been made when one side of a lamp has an electrode voltage of about twice the other voltages.

4.2 Light regulation with HF ballasts

4.2.1 General: block and circuit diagrams

Besides the standard range of HF ballasts, Philips offers a range of dimmable fluorescent ballasts that allow for the adjustment of lighting levels to suit personal preferences whilst at the same time providing the opportunity for additional savings on energy.
Compared with the standard HF ballast, an additional light regulation circuit is incorporated, that varies the operation frequency for the lamps, according to the regulating input voltage (see Fig. 78). The control voltage is supplied to the connections '+' and '–' at the HF-R ballast and to the connections 'DA' for the HF-R DALI (Digital Addressable Lighting Interface) version.

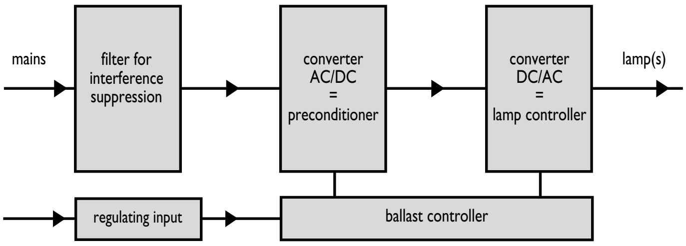


Fig. 78 Block diagram for an HF regulation ballast.

Operating switches S1 and S2 (see Fig. 79) at a higher frequency results in a lower lamp current, and so the light output decreases.

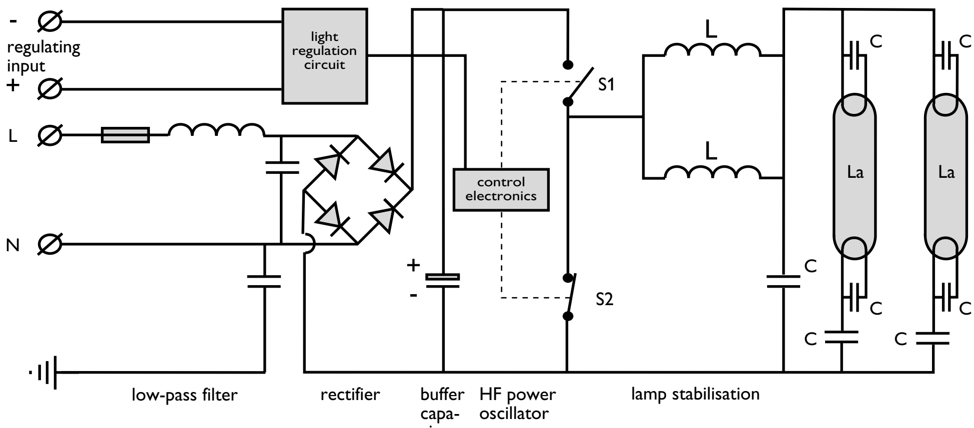


Fig. 79 General circuit diagram of an HF ballast for light regulation.

There are nowadays two ways to supply the control voltage to the regulating ballast, namely analogue and digital. The most common is analogue in which the input voltage for the light regulation circuit may vary from 0 V to 10 V DC: 1 V results in a minimum lighting level and 10 V in a maximum lighting level.
In addition to the analogue dim input, a digital dim input is used in the DALI ballast.
The major European ballast and controls manufacturers support both of these systems, which guarantees compatibility between the various controls and ballasts.

4.2.2 The dimming process

The nominal operating frequency of the Philips ballasts is around 48 kHz. At this frequency the lamp reaches its nominal 100 % operating values. The ballast controller can, activated by the light regulation circuit, vary the operating frequency between 48 kHz and 90 kHz.
Basically, the regulating process can be understood as follows: At higher operating frequencies the impedance of the lamp current stabilisation coil L increases, resulting in a lower current (see Fig. 80). At the same time, the impedance of the capacitor C across the lamp decreases (capacitor impedance = $1/\omega C$, with $\omega = 2\pi f$).
The electrode current is a prerequisite for stable regulation of the lamps. Operating switches S1 and S2 (see Fig. 79) at a higher frequency results in a lower lamp current, and so the light output decreases.

The electronic regulating ballasts contain more complicated circuits to optimise these currents within the operating area, with the lowest possible power.

4.2.3 Ignition and re-ignition

The Philips dimming ballasts are always of the warm-start type with a defined preheating time (see Section 3.3). If an installation with a ballast for light regulation is switched on at a low setting, the normal preheating current will flow for about a second, so that a warm start is guaranteed under all circumstances. Once the lamps have started, they will dim down or up to the previously set position. This is done automatically within about 0.1 second.
The minimum lamp power for 'TL'D and PL-L lamps is 3 %. It is expected that these limits will decrease to lower levels (1 % for 'TL'D) with the next generation of regulating ballasts.

4.2.4 Ballast types

All dimming ballasts are of the preheated and stand-alone version, fully electronic and of the constant-wattage type (see also Section 4.1.5).

4.2.5 Harmonic distortion

The absolute value of the harmonics of the mains current is independent of the regulation setting with all dimming ballasts. This means that the harmonics in the mains current, expressed in mA, are approximately constant.
When the power is regulated, the fundamental (50 Hz component) of the mains current will decrease to a lower level. The harmonic currents, expressed in percentages of the fundamental, will therefore increase. This results in a THD (Total Harmonic Distortion) value at the minimum setting that can be 2 to 4 times higher than when in full operation. Normally this causes no problems for the lighting installation, as the effective current through the cabling and switchgear is lower when regulating than when in full operation.

4.2.6 4.2.6 Power factor

The lamp power decreases during dimming, so the power consumption from the mains drops. However, the losses in the ballast and the electrode preheating (necessary for stable regulation) are maintained. The mains power and mains current of all dimming ballasts vary more or less according to Fig. 80. This results in a shift of the power factor from >0.95 leading to lower values (0.7 leading for HF-R at minimum setting). Again, this normally causes no problems (see former section). However, where the power is supplied by a generator or a similar device, care should be taken to ensure that the power supply can properly handle the lower capacitive power factor and the higher harmonic distortion.

4.2.7 Electromagnetic compatibility (EMC)

Basically, Section 2.3 applies. This means that over the entire dimming range the interference levels will meet all relevant international standards when the ballast and the luminaire are properly installed (see also Section 2.3.4).

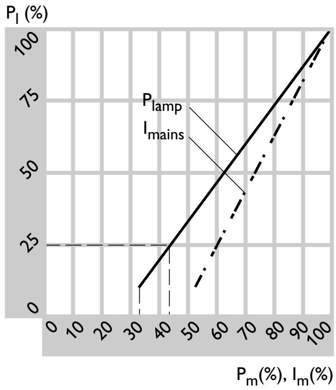


Fig. 80 Mains power and mains current as a function of the lamp power.

The interference conducted through the mains will never cause problems in practical situations. The radiated interference, however, cannot be totally neglected and it is still possible that some electronic device will pick up the radiated stray field of the HF lighting system. Whether or not interference will actually happen will depend, of course, on factors such as:
- the sensitivity of the receiving system
- the frequency band to which the receiver is tuned
- the distance and direction with respect to the HF luminaire
- the presence or absence of a screening on the HF luminaire.

In 'full light' operation the higher harmonics of the operating frequency are fixed at certain values. However, when the light is regulated up or down, these higher harmonics become frequency bands and may coincide with a radio or TV transmitter frequency. In most cases, TV and FM radio signals are not affected, but AM radio signals can be. Should be this the case, a practical solution has to be found to the interference problem e.g. by extra screening or creating more distance. Also, some low-frequency paging systems operate in the frequency range from 48 kHz to 90 kHz, used for the dimming ballasts. See also Section 4.1.19 Installation aspects.

4.2.8 Starting and operating temperature

Unlike HF ballasts without light regulation, the starting temperature for the most regulating ballasts is from +10 to 50 °C.
At low lamp tube temperatures, the light output of the fluorescent lamps is low (see Section 3.7), in which case dimming of the lamps is not effective. Moreover, striations and flicker may occur. For optimum regulation, the tube wall should reach a temperature of approximately 40 °C (45 °C for 'TL'5). In cold or outdoor applications, fully-enclosed luminaires should be used, and before regulation can start the lamp must have operated on full power long enough to warm up the air in the luminaire. Additional measures, such as an extra plastic tube around the lamp or extra heating by resistance wire, may be necessary.

4.2.9 Input voltage versus light output with analogue ballasts

With the analogue versions of HF ballasts, the control-input circuit is a current source mode circuit. This means that the control voltage is generated in the input circuit of the HF-R regulating ballast itself, see Fig. 81.

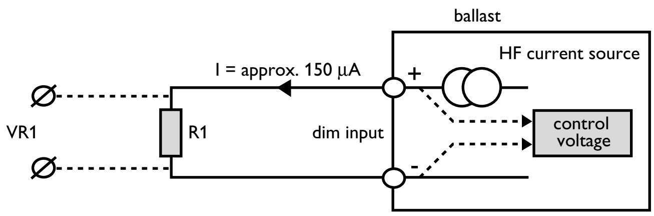


Fig. 81 Current source dim input of analogue ballast.

If the control input is not connected, the unit is in the 100 per cent light position (open circuit for the control wiring, resulting in 10 V on the control input terminals). If the control input is short-circuited (0 V on the input terminals), the setting is at minimum lighting level. An external control voltage is not necessary. By inserting a potentiometer, continuous regulation can be achieved in a simple way. The control current that can be delivered by the regulating ballast is 0.14 mA for the HF-R type. To cover the control voltage range from 1 to 10 V the potentiometer must vary its resistance between certain values, (see accompanying table), depending on how many ballasts are connected:

Number of ballasts	**For HF-Regulator ballast**		
	I_{max}	R_{min} <	R_{max} >
1	0.15 mA	6.7 kΩ	100 kΩ
5	0.75 mA	1.5 kΩ	20 kΩ
200	30 mA	40 Ω	0.5 kΩ

The relationship between the lamp power and the control voltage is shown in Fig. 82.

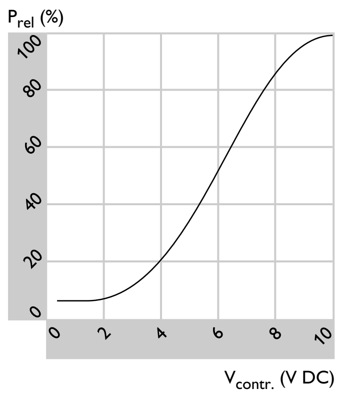


Fig. 82 Relationship between lamp power and control voltage of analogue ballast.

The regulation curve can be obtained with a simple potentiometer. Philips developed the LPS range of potentiometers (LPS = Light Potentiometer Switch), which feature regulation curves between 3 and 100 per cent light level irrespective of the number of ballasts connected.

When the complete regulating range is not required the maximum and/or minimum levels can be set with the use of Zener diodes. At least seven ballasts are necessary to deliver the bias current of 1 mA (see Fig. 83).

The maximum number of ballast is limited by the power dissipation of the Zener diode employed.
To set a fixed minimum level the zener should be placed in series with the control voltage, see Fig. 84.

For example, a Zener of 3.9 V giving a minimum light level of approximately 20 per cent.

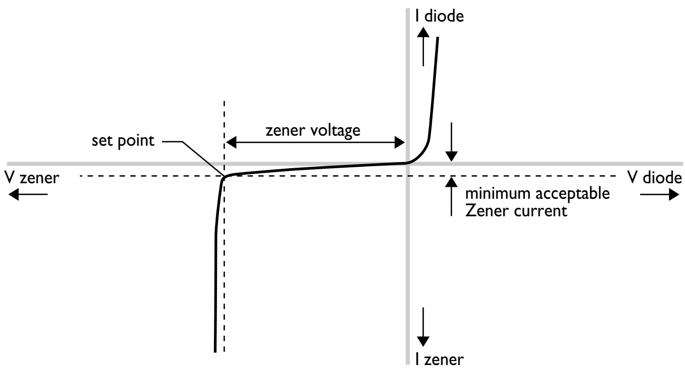


Fig 83 Zener voltage characteristic.

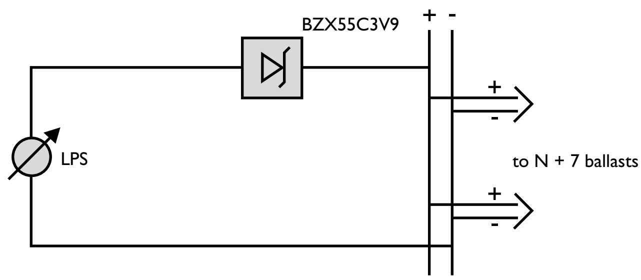


Fig. 84 Minimum dimming level setting with Zener.

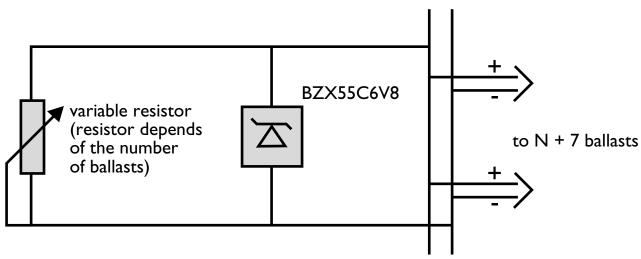


Fig. 85 Maximum dimming level setting with Zener.

By placing the Zener in parallel to the control voltage, the maximum light level is limited. For example, a Zener of 6.8 V will give 70 per cent light output, see Fig. 85.

An external control voltage can also generate the control voltage, in which case the '+' should be connected to the '+' of the ballast. Care should be taken that the external control circuit has an output that is of the 'current sink' type.
Also, an AC-ripple on the control voltage should be avoided, as this may adversely affect the performance of the system.

The power rating of the potentiometer or the external control voltage source must be in accordance with the number of ballasts and the maximum control current (1.5 mW per HF-R ballast).
The length and the diameter of the control cabling must be dimensioned such that the voltage drop over this cabling is less than 0.5 volt.

4.2.10 The digital DALI (Digital Addressable Lighting Interface) ballast

The main differences with the standard HF-R ballast are:
1. The control input has no polarity and is protected against accidental mains power voltage.
2. The ballast contains a smart chip for communication via the DALI protocol.
3. The ballast itself incorporates the switch-off function, so no external switches are necessary.

DALI ballasts must be connected to a DALI controller.

Introduction

For regulating ballasts (HF dimming), the analogue 1-10V DC dimming interface is the most common on the market. Although sufficient in many applications, this system does have some drawbacks:
- power setting only, switching must be done by a second separate control circuit
- control circuits must be hard-wired because ballasts cannot be addressed
- ballast feedback is not possible
- signal degradation on long lines
- poor definition of minimum light level (different ballasts can give different light levels at the same control voltage level).

In order to establish a widely accepted alternative for this interface, in 1996 a group of European lighting companies started working on a digital interface in a COMEX workgroup comprising members from Helvar, Hüco, Luxmate, Osram, Philips, Tridonic, Trilux, Vossloh-Schwabe. Also ECS, Fagerhult, MagneTek, Insta, Eckerle, Niko Altenburger and Hadler. A key feature had to be the possibility to make each ballast addressable while connecting them in parallel on the two control lines.

Because the digital interface was intended for the lighting business only and should be able to address the ballast individually, DALI (Digital Addressable Lighting Interface) was born. DALI should lead to a standardised digital interface. This will give the benefit to get one common specification for control manufacturers and installers. For the customer it gives the possibility to connect

different makes of ballasts to one control system, and for the manufactures it will lead to a joint effort of platform development.
Like the 1-10 V DC interface, the DALI also works with two wires. The installation is thus much the same as for the analogue interface, e.g. similar wire types and connectors can be used. The major difference is the control signal regulates and switches the circuits.
With ballasts addressing, this allows the control circuits to be independent of the power circuits. Besides sending commands to a ballast, it is also possible to get information from a ballast (two-way communication).

The DALI protocol supports a variety of commands, the most important of which are:
- setting the light level
- remote switching on and off
- storing and recalling pre-set levels.

Commands can be addressed to a single ballast, to a group of ballasts, or to all ballasts connected to the control lines.

Beside commands, there also are queries modes such as:
- query status
- query lamp failure.

The information received from the ballast can be used to diagnose problems occurring in an installation.
A third category of commands was defined to set up the installation. This includes assigning addresses and group numbers.
Finally there is a category of reserved codes for future extensions to the command set.

Light control

When defining the standard, a firm decision was taken not to develop a complex building-control system with maximised functional capabilities, but to create instead a simple system with clearly-defined structures. DALI is not designed to be a complex BUS system, but rather for intelligent, high-performance light management in a local zone. These functions can of course be integrated into a building management system by means of suitable interfaces.
Since the DALI protocol has been designed for rooms requiring professional light management, the following functions have been defined:

Switching on / off
Maximum 64 individual DALI electronic ballasts in a single system (= with one master controller) can be switched on / off as there are a maximum of 64 different addresses. The actual maximum will depend on the controller used. For the TRIOS DALI controller this number is 20.

Dimming
The dimmable electronic DALI ballast is equipped with a technical facility for dimming the lamp current logarithmically from 100 % to 0.1 % in 254 dimming steps (in practice, the lower dimming level is set in the ballast. It is currently set at 3 % so as to ensure that the lamp service life is not compromised. Therefore, in practice, about 125 steps are used). See Figs 86 and 87.

Light scenes
Up to 16 light scenes can be programmed and retrieved in a single DALI system. Again, the practical number depends on the controller used. For the TRIOS DALI controller this number is 5.

Status display
The DALI protocol can also be used to display and / or retrieve statuses of the electronic ballast or lamp.

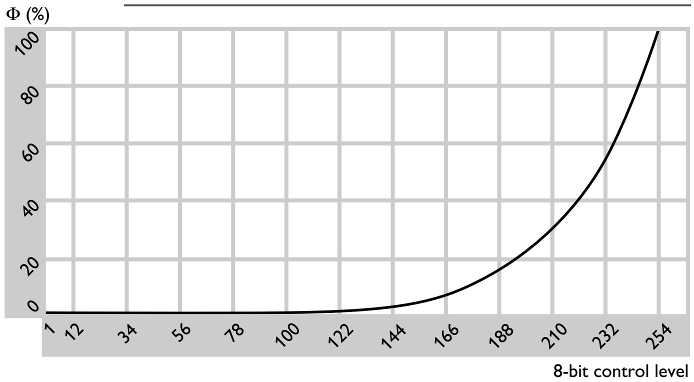


Fig. 86 Logarithmic dimming curve with minimum dim level 0.1 % in 256 steps.

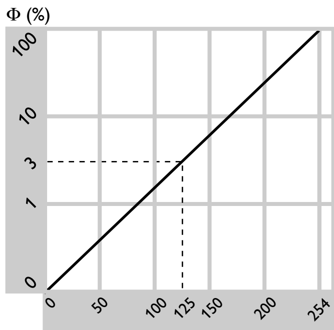


Fig. 87 Logarithmic dimming curve DALI ballast.

The DALI protocol control power is supplied by the control system.
A DALI interface can be roughly split into two main parts:
- DALI hardware
- DALI software

The DALI hardware forms the interface between the control lines (sometimes erroneously called "buslines") and the intelligent (e.g. microcontroller) module of the ballast. The DALI software, which "runs" in the intelligent module, takes care of the execution of the commands that lead to actions in the ballast e.g. increase of lamp power, switch-off of the lamp, answer to a query from the DALI master, etc.

DALI Hardware

The signals on the DALI control lines are single pole. This means that the DALI control voltage is polarity sensitive. The connection of the DALI control lines to the interface terminals is marked with "DA" for data, because the input is made polarity insensitive (see Fig. 88).

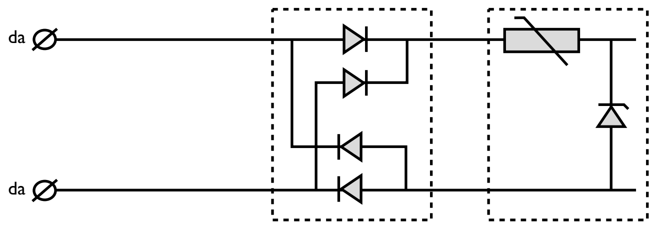


Fig. 88 Mains protection and polarity insensivity DALI ballast.

Because the DALI terminals look the same as the mains terminals, caution must be exercised when the installation is being connected. To prevent damage caused by interchanging the DALI control lines and the mains, the DALI system is equipped with extra hardware in the interface that can withstand the mains voltage (see again Fig. 88). Because a number of ballasts, connected to different mains phases, can be connected to each other by means of the DALI input, all DALI inputs are isolated from their HF inverter inside the ballast. This isolation is done in the ballast by means of an optical isolator (opto-coupler). The ballast backward channel switch, which is controlled by the intelligent module (microcontroller) of the ballast, short-circuits the DALI control lines.
The short-circuit current of the DALI control lines, which is generated by the DALI master, is therefore limited. The current is limited to 250 mA. The maximum voltage drop is limited to 2 volt for the DALI line.

Fig. 89 Bi-phase encoding.

Digital control

The electronic ballasts are connected to the controller via two wires. Data packets consisting of 19 bits enable the controller to communicate with the electronic ballasts at an effective rate of 1200 bauds per second. A message is built up by 1 start bit, 16 data bits and 2 stop bits (see Figs 89 and 90).

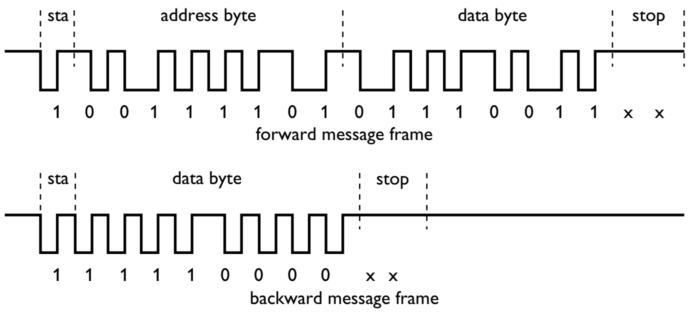


Fig. 90 DALI message frames.

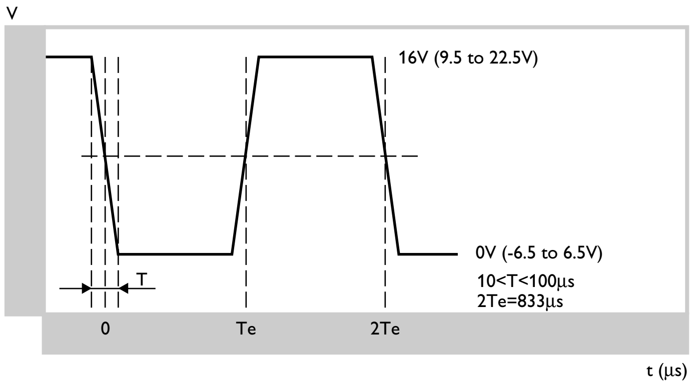


Fig. 91 Tolerances of DALI line voltage.

The DALI line has a voltage of 16 V, with the tolerances shown in Fig. 91.

The current in a DALI controller is limited to a maximum of 250 mA in accordance with IEC 929. The current consumption per electronic ballast is set at 2 mA.

The DALI Ballast

The architecture of digital ballast is shown in Fig. 92. The solid lines depict power signals, the dashed lines depict control and sensor signals. The microcontroller is the central unit in the digital ballast. It receives commands from the DALI control lines via a transceiver unit, which is essentially no more than a voltage scaling and protection unit.

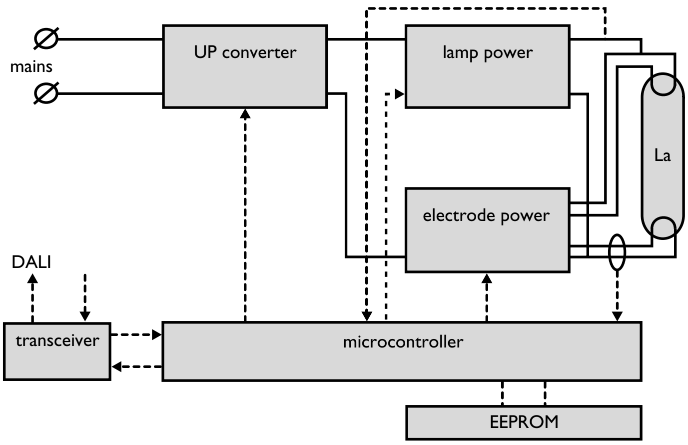


Fig. 92 Architecture of Digital Ballast.

The ballast has three power converter units.
An up-converter acts as a mains preconditioner, and two half-bridge converter modules drive the lamp. The first one generates the arc current, the second one drives the electrodes or filaments. Both half-bridges receive their drive signals directly from the microcontroller. The microcontroller receives lamp current and voltage signals from sensors in the power circuit. The microcontroller can store data that are not to be lost when the ballast is disconnected from the mains in a non-volatile memory such as an EEPROM.

With this architecture many advantages are obtained:
- arc and filament current are uncoupled and can be controlled separately: improved lamp life.
- operating points for different lamp types can be stored: multi-lamp ballast.
- all control loops and signal processing is moved into the microcontroller: reduced component count, higher reliability, better accuracy, miniaturisation.
- high design flexibility: changes often require only software adjustments because hardware is replaced by software.
- DALI interface is integrated in the ballast rather than being added to it: optimal use of functionality.
- ballasts can report problems such as lamp failure.

This type of HFR ballast can be called "digital" both internally end externally: internally, because the power conversion processes are controlled digitally, externally because of the DALI interface.

Switching in the electronic ballast

The lamp is switched on/off in the electronic ballast. This means that there is no longer any need to use power switches to interrupt the circuit. The 230 V supply voltage is always available at the electronic ballast (also in the OFF situation), and light can be switched or dimmed by means of a command via the DALI line.
All ballasts are always connected to the mains, but can be divided over the three phases.

Addressability

Up to 64 addresses can be assigned in a DALI system. This means that 64 different electronic ballasts can be controlled independently of each other. Addressing must be performed after the system has been installed. The addressing procedure is dependent on the controller. A second system is necessary if more than 64 luminaires must be switched or regulated. The maximum number of ballasts is 125 if they do not all require different addresses.

Light groups

The addressed ballasts or luminaires can be combined into light groups. A group is a number of ballasts with the same switching/dimming behaviour (like a hard-wired circuit). Up to 16 groups are possible for each DALI line. With the analogue HF-R ballasts there should be 16 different control-signal cables, but DALI can do with one control-signal cable.

Simple installation

No special wiring such as twisted pairs or special cables is required for installing a DALI line. Twin control wires in existing installations can also be used as DALI lines.
It is important to ensure that the maximum voltage drop does not exceed 2 V.

4.2.11 Installation aspects

The following aspects regarding installation should be considered:
- The regulating ballasts can be distributed arbitrarily over the individual phase conductors of a multi-phase network, regardless of the regulating element used.
- The control circuit leads should be separated from mains and lamp cabling. They should not be bundled.
- All connection leads between the control inputs of the electronic ballast on the one hand and between amplifiers, light sensors, electronic potentiometers and control buttons on the other hand should be laid out as for nominal mains voltage. Extra low-voltage control wiring is not allowed.
- External cabling for mains, control signals and possible telecommunication systems should be so installed that no mutual interference can take place. Please refer to IEC 364 Chapter 522.
- Master-slave is only allowed for a continuous row of luminaires, where the distance 'D' is no more than a few centimetres, see also Section 4.1.13.
- If, in the case of an external control voltage source, the polarity is reversed ('+' connected to '-') with the analogue dimming ballasts, no damage will result, but full regulation will not possible. The lower lighting levels will not be reached.
- For two reasons, the minimum cross-section of the control wire is 0.5 mm^2: This is the minimum allowed for the conductor, and thinner wires are not strong enough to be pulled through the conducts.
- The control input of analogue ballasts is protected against accidental mains voltage connection by means of a PTC (see Fig. 93) and with the DALI ballasts by a diode bridge (see Fig. 88).
- Although it is not required by international standards, it is recommended that the optics (mirror) in a luminaire become connected to the earth. This will minimise the EMC levels and can improve the behaviour at minimum dim level.

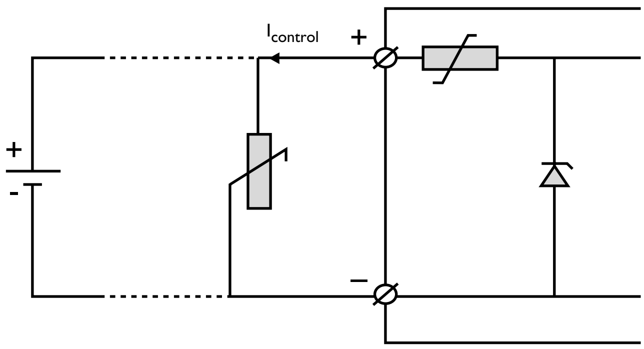


Fig. 93 Dim input protection with a PTC for analogue ballasts.

4.3 Control possibilities

Most ballasts are built into luminaires, many of which are controlled by a more or less sophisticated control system in order to achieve optimum performance in respect of energy saving, adequate task lighting and/or visual comfort. This means that messages for switching and/or dimming of the lamps have to be transmitted to the ballasts in the luminaires.
Messages can be generated manually via:
- switches, push-buttons or potentiometers
- infrared transmitters
- a keyboard connected to a computer with an appropriate program

Or automatically via:
- timers/clocks
- movement detectors
- light sensors
- digital input/output interfaces
- computer programs.

The most simple system of control is by a switch connected to the lamp-circuit supply voltage and a potentiometer to the ballast's dimming input. It is possible to regulate up to more than 100 HF-R ballasts for light control simultaneously with a single Philips potentiometer LPS 100 – see also Section 4.2.9. The integrated switch of the LPS 100 can switch only a few luminaires. Although the maximum load is 10 A, the number of ballasts is limited by the inrush current of the ballasts. If more than the allowed number of luminaires have to be switched, an additional contactor (preferably with a spark suppressor circuit) has to be installed (see Fig. 94).

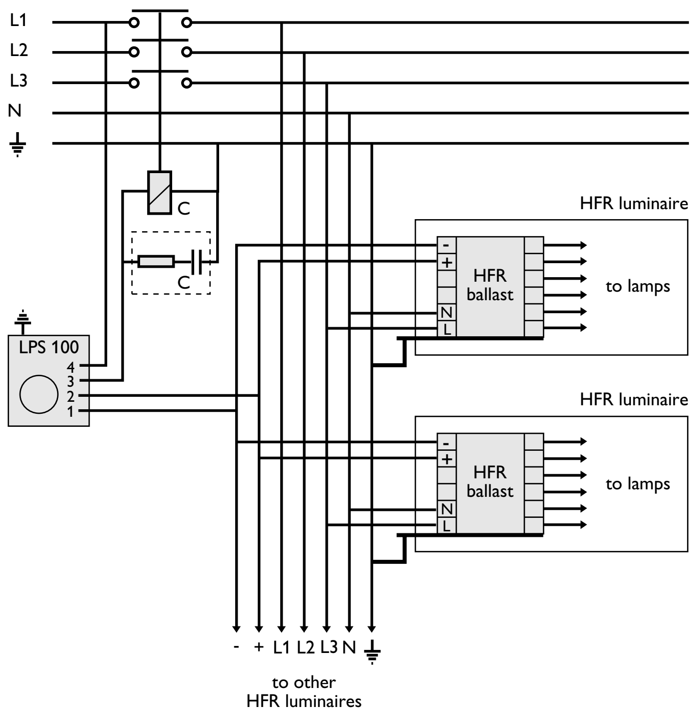


Fig. 94 Manual HF regulation.

In many cases, however, manual operation is not sufficient to meet present-day requirements. The lights often have to be switched according to the presence or otherwise of people (using movement detectors), or in response to momentary daylight contribution (using a light sensor). With infrared remote control, a great deal of flexibility is achieved, while installation costs are reduced, as vertical (mains) wiring is made redundant.
Using these versatile system components, Philips Lighting can offer optimum, custom-designed control solutions.

The control systems and products can be divided into four main categories:
- Luminaire-based solutions: stand-alone control, for (a part of) a single room
- Room-based solutions: TRIOS for active control of stand-alone offices, Scenio for effect-oriented solutions, TRIOS DALI.
- Lighting Management Systems, such as Helio, LM 100 (Lightmaster) and WM 8000 (Wiremaster), for complete buildings
- General purpose products, such as dimmers, transmitters, receivers, sensors, push-button interface, manual potentiometers, movement detectors.

For all products and systems there are product data sheets, installation instructions, specification guides and/or handbooks available. These should be studied carefully before designing and installing any of the various control systems. There are also special application courses, which can be followed on request.

This section is not intended to cover all aspects of controls. Consequently, only a brief description of the various products and systems is given below.

4.3.1 TRIOS luminaire-based controllers

The switching and/or dimming signals for the ballast are generated by a simple sensor or by a controller, which, together with the sensors employed, is built into the luminaire. The luminaire is connected to the mains supply only. The Philips programme comprises four solutions: TRIOS Luxsense for HF-R; TRIOS Multisense for HF-R; Chronosense Controller; and TRIOS Infrasense for HF-R.

1. TRIOS Luxsense for HF-R

The most simple system for a downlight luminaire: just one component!
The Luxsense (see Fig. 95) is a very discreet light sensor that reduces (in combination with a HF-Regulator ballast) the light output when the illuminance level of the workplace increases above a pre-defined level. There is no switching function.
Two clips are available for easy mounting of the component on ‘TL’D or ‘TL’5/PL-L lamps. (Note: the Luxsense cannot be used in combination with ‘TL’5HO – too hot!) In the case of ‘TL’D, the Luxsense must be mounted at the electrical "cold" side of the lamp, and with ‘TL’5 at the labelled end of the lamp, at least 5 cm. from the end cap of the lamp. The "cold" side corresponds to the side of the ballast that allows the longest leads (Fig. 95). It also can be clicked to the lamella of the luminaire optic, using a special bracket (provided by the customer). It is connected to the 1-10 Vdc control input of Philips HF-R ballast and can regulate up to 20 luminaires.

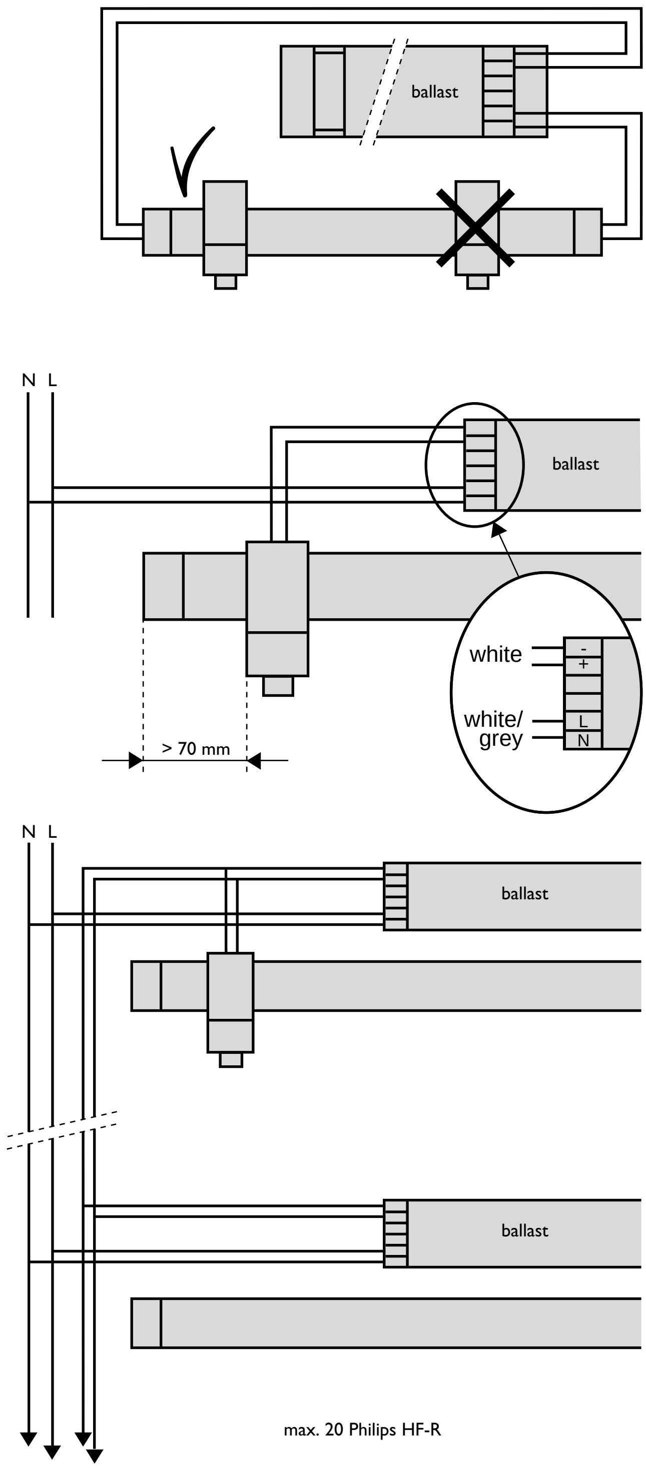


Fig. 95 Light control with TRIOS Luxsense.

The sensor is optimised for use in applications where 600 lux is installed and 500 lux is required, with an assumed reflection factor of the room of 30 per cent. However, actual circumstances may differ, so to compensate for this, the sensitivity of the sensor can be adjusted manually over a range from 1/3 to 3. Therefore the minimum required reflection factor of the room must be 10 per cent, which is met by most practical conditions.

Proper control operation is based on the condition that Luxsense controls at least 80 per cent of the artificial light it 'sees'. This can be critical in applications including a large amount of indirect light from other luminaires.
The Luxsense does not provide a constant lux level, but it does compensate for excess daylight by reducing the artificial light level by approximately 50 per cent of the excess.

2. TRIOS Multisense for HF-R

The luminaire-based controller and multi-sensor are intended for integration in luminaires, thus adding control functions to the luminaire without consequences for the electrical installation.
The multi-sensor is designed to fit on various types of mirror using a special bracket. The controller can be mounted inside a luminaire.
The multi-sensor LRI 1110/10 contains a movement detector for maximum energy saving, a light sensor for ambient light linking, and an infrared receiver for manual remote override control from a wall-mounted transmitter or a hand-held unit (Fig. 96). The infrared receiver can also be used for commissioning or remote programming of lighting levels.

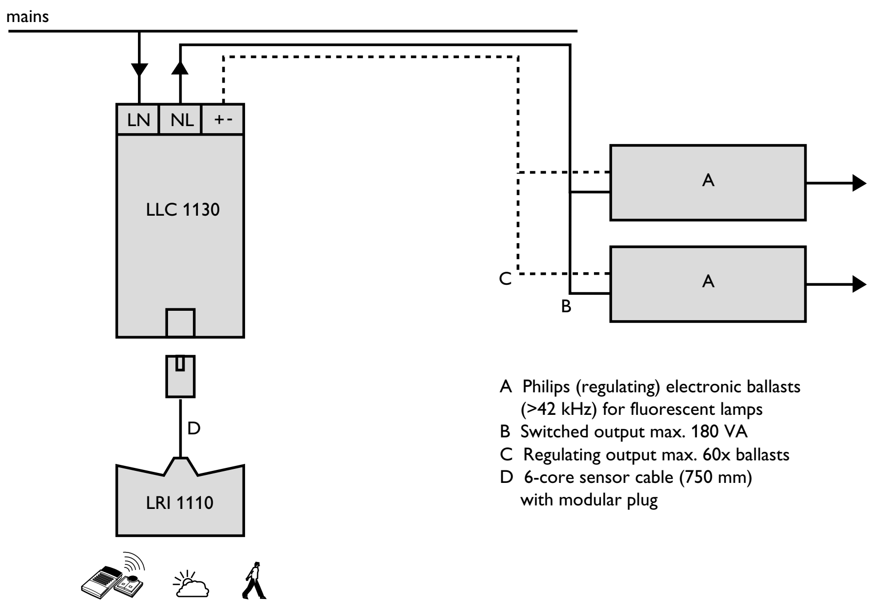


Fig. 96 Light control with TRIOS Multisense.

The controller LLC 1130/20 is designed to switch conventional or electronic ballasts up to a load of 180 VA. The output terminal provides the 1-10 Vdc for the control of a maximum of 60 regulating electronic ballasts.
These types of luminaires, containing all three sensors, combine maximum energy saving and comfort with minimum installation time.

The LLC 1130 controller must be used in combination with the luminaire-based multi-sensor LRI 1110. Where the information on presence and light level is not required, the controller can be used in combination with the infrared receivers IRR 8125 or IRR 1224.

The IR remote control facility is also used for programming the group address and channel address of the controller, as well as the mode of operation. For this purpose the IRT 1090 programming transmitter is required. Alternatively, the two-key transmitter IRT 8050 in "teach mode" can be used.
The multi-sensor is fitted with a cable and a modular plug for connection to the modular input socket of the controller.

The combination of LLC 1130 and LRI 1110 delivers maximum energy savings by daylight compensation and presence detection with the manual overrule feature with the IR remote control.
The combination of LCC 1130 and IRR1224/8125 gives flexibility to the installation (no vertical wiring for switches) with the manual control via IR remote control.

Modes of operations, selectable with the programming transmitter, determine the switching and regulating behaviour of the luminaire. The modes (5 in total) correspond with typical applications: a test mode, a mode for constant-lux applications, a mode for security lights, a daylight-link mode, and a mode for maximum energy saving.

Related equipment

IR transmitter
• Two-key transmitter IRT 8050
• Four-preset hand-held transmitter IRC 2130
• Programming transmitter IRT 1090
• Infrared receiver IRR 1224

3. Chronosense Controller

The Chronosense is a device intended for integration in an outdoor-type luminaire (street lighting, floodlighting, etc. or for fitting onto a gear tray that is mounted at the bottom of a pole. It contains a relay to switch a conventional extra "dim" ballast or a ballast type with "tab" for SON-T lamps 70 W to 400 W (see Fig. 97) in order to obtain 50 per cent light level during night-time periods of relatively-low traffic density. This saves energy while maintaining a homogeneous spread of light over the complete application.
By means of dip switches, the device must be programmed for the time intervals for 100 % and 50 % operation (see Fig. 98), and it contains a test mode to check the functionality.

The housing is IP20 with extra precautions against the ingress of dust and insects. Additional measures have to be taken against dripping water when mounted in a lamp-post.

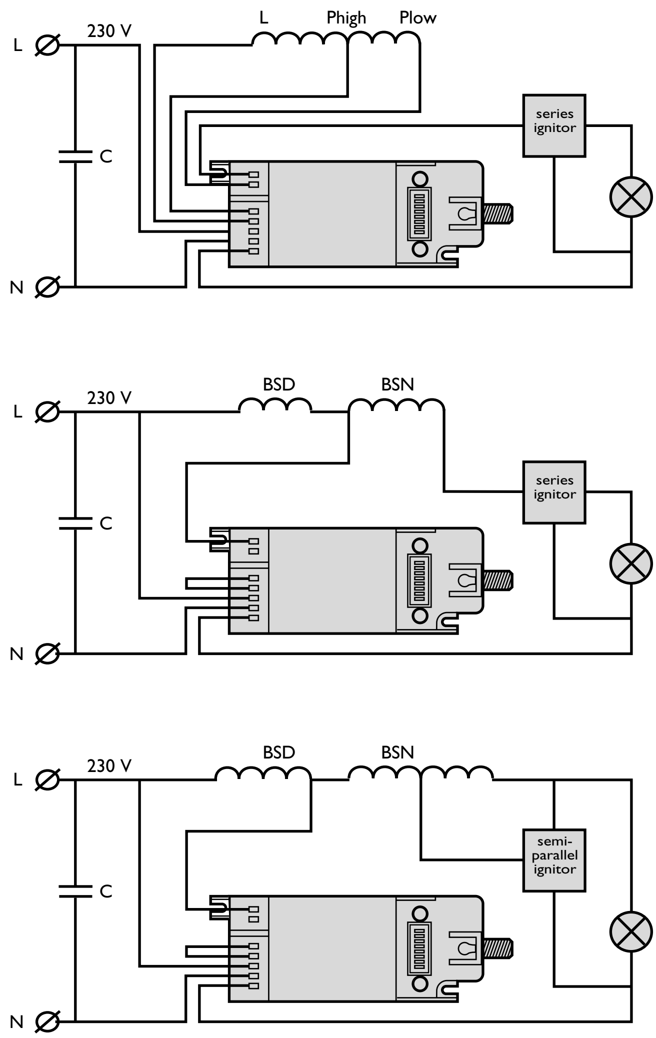


Fig. 97 Connection diagrams: Chronosense.

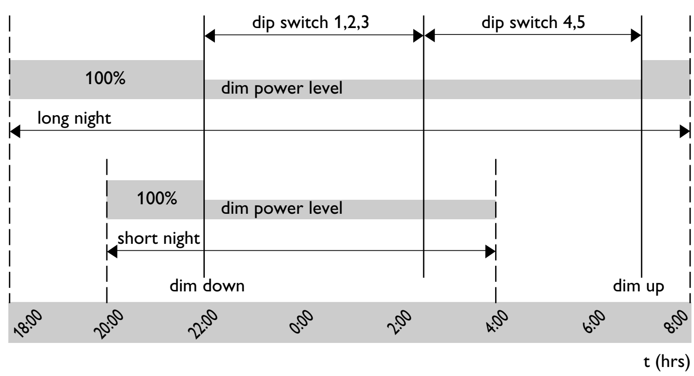


Fig. 98 Example switching and dimming programme: Chronosense.

4. TRIOS Infrasense for HF-R

The system contains three components (see Fig. 99):
1. The infrared receiver IRR 1224, which, like the Luxsense, can be mounted in a luminaire. It is connected to:
2. The Infrasense controller LLC 1120, which has two switched outputs for 400 VA (any type of lighting load). There is no dimming function.
3. The two-key wall transmitter IRT 8050

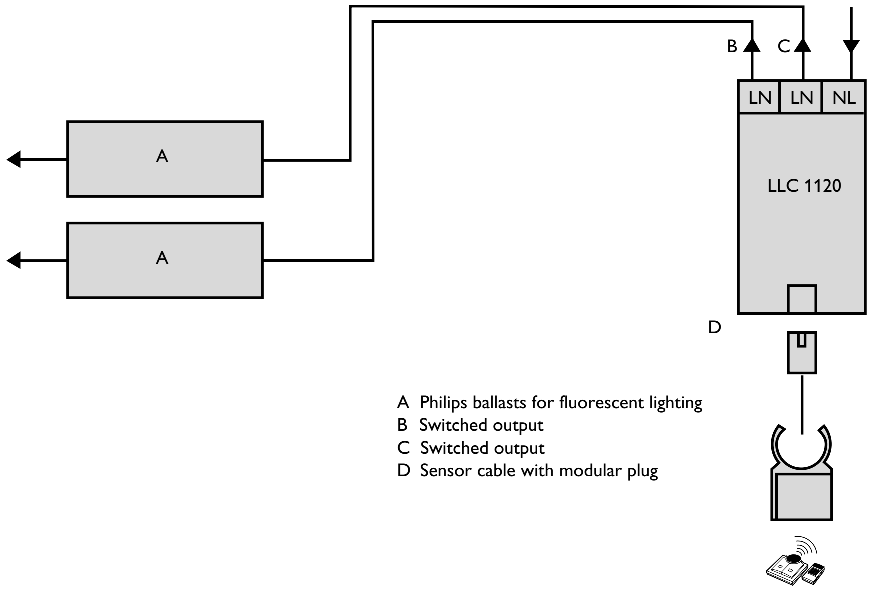


Fig. 99 Light control with TRIOS Infrasense.

The controller can also be connected to a movement detector for automatic on/off switching.
The controller has the capability for simple control of curtains and projection screens. The infrared codes for this application are implemented in the LLC 1120 and the IRT 8050. It can switch two channels of conventional or electronic ballasts with a total lighting load of 400 VA. The behaviour of the controller can be programmed using the TRIOS programming transmitter IRT 1090 or the two-key transmitter IRT 8050 in the "teach-mode".

Applications

Infrasense offers basic energy savings solutions in three different ways:
1. Two (50 % - 100 %) and three (33 % - 66 % - 100 %) different light levels can be realised by switching on the first, the second or both channels, whereby the channels represent one and two lamps (in the case of three-lamp luminaires) or two lamps each (in the case of four-lamp luminaires).
2. Central switch-off commands by power interrupts.

Infrasense offers office flexibility by eliminating the need for vertical wiring (but using infrared remote control instead). Rearrangements of the offices can easily be realised by re-addressing the Infrasense controller using the programming transmitter. Infrasense is based on the standard TRIOS group and channel address scheme.

4.3.2. Room-based solutions

1. Occuswitch

The Occuswitch operates entirely stand-alone and does not have an interface to other building systems. The Occuswitch is available with screw and Wieland contacts. The type 1050/1051 contains a movement detector with a built-in light switch. The types 1060/61/ (presence) and 1064 and 65 (absence) also contain an infrared receiver. For details, see the product leaflets.
The LRM 1050 is designed for the automatic switching of any light load for maximum 10 A rms (2300 VA), in indoor applications only.
The detector has dip switches that enable the end-user or installer to alter its functionality even after installation. The sensor has a built-in "daylight override" function. This function will prevent the unit from switching on the light when sufficient daylight is present, regardless of the detection of movement. The override function can be enabled/disabled by a dip switch and adjusted by turning the potentiometer or pushing the button.
The sensor has built-in intelligence that adjusts the sensitivity according to the needs of the moment. When the unit detects that somebody is present, it increases its sensitivity, preventing it from switching so long as that presence continues. When the unit detects that nobody is present (longer period of time), it decreases the sensitivity, preventing the lights from switching on without reason (preventing false triggers).
The sensor is optimised for recessed ceiling mounting. The sensor has a clearly-defined circular detection pattern with a footprint diameter of seven metres at a mounting height of 2.7 metres (see Fig. 100).
The light sensor used has a dynamic range of between 10 and 1000 lux.
Two Occuswitches can be connected in parallel; as, for example, in a long corridor (see Fig. 101).

Presence detection means:
- Automatically 'in' when movement is detected and light level is too low
- Automatically 'out' when after a certain time no movement is detected (or light level is increased above the set limit)

Absence detection means:
- No automatic IN, but must be done by infrared or switch
- Automatically OUT when after a certain time no movement is detected (or light level is increased above the set limit)

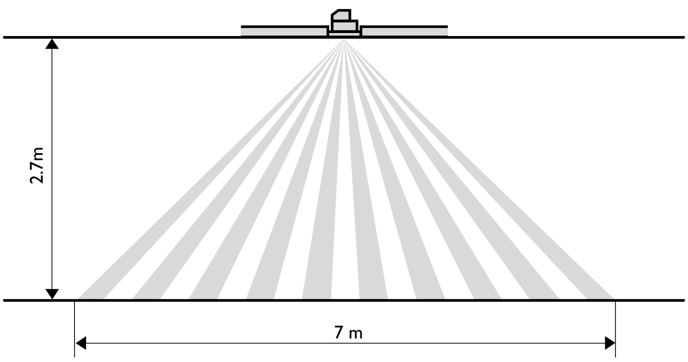


Fig. 100 Working area: Occuswitch.

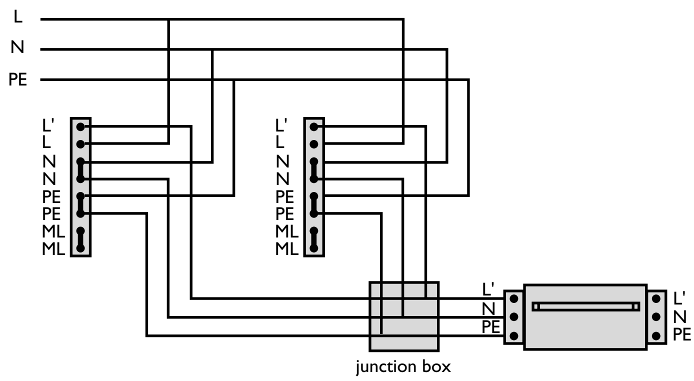


Fig. 101 Connection diagram: two Occuswitches in parallel.

2. TRIOS and Scenio

TRIOS

The switching and dimming signals for one set of luminaires are provided by one addressable TRIOS controller LRC 1020/1025, while type LRC 1010/1015 only provides switching signals. The luminaires are connected to the switched mains supply for 5 A maximum and to the dimming control signal of 1-10 Vdc of the HF-R ballasts. Several sensors can be connected to one controller. TRIOS controllers can function independently of each other with their own set of sensors (Fig. 102). The set of sensors can be shared by a maximum of five controllers in order to control five different sets of luminaires (channels). Channel address setting is obtained with an infrared-programming transmitter. A channel is a group of luminaires that identically switch and dim together. Looking at the end result, a channel looks like a hard-wired circuit.

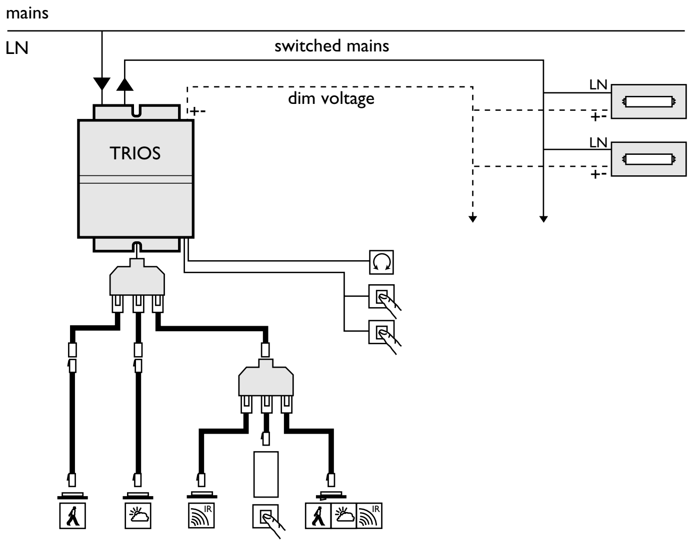


Fig. 102 Wiring diagram: TRIOS controller with sensors.

Four pre-defined lighting situations (presets) are possible, while the lights can be switched from multiple points, and levels can be adjusted, stored and recalled with the four-preset transmitter. This system is mainly used in single or open-plan offices, reception areas, corridors and staircases.

The controller is available in two versions: the installer box version, which can be placed above a ceiling, and a DIN-rail version, for mounting in an installation cabinet.

Scenio

Scenio is a modular lighting control system that can readily be tailored to suit a particular lighting requirement. The light controller LRC 1555/1505 can be looped through with a number of extension modules to control up to 32 sets of different luminaires with incandescent, halogen and fluorescent lamps. Non-lighting equipment can also be switched directly via the output relays. Potential-free contacts are provided enabling AC and DC switching.

Up to 16 preset lighting scenes can be stored in a memory and recalled by the user. One or more infrared receivers can be connected to the light controller for infrared remote control from any position in the room. A movement detector can be connected for automatic switch-off and on (Fig. 103). Parameter setting is done with a special infrared-programming transmitter. Programming and selection of presets is done with the normal remote control transmitter. The system is very suitable for applications requiring a frequent change of lighting scenes, as in conference rooms, auditoriums, bars and restaurants, hotel lobbies and galleries.

The controller is in a DIN-rail housing, for building into cabinets.

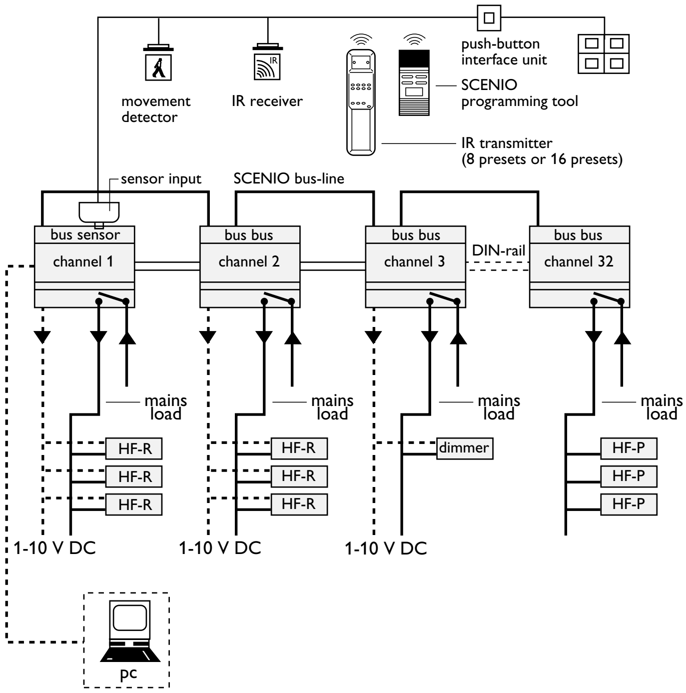


Fig. 103 Scenio modular lighting control system.

3. TRIOS DALI

TRIOS DALI LRC 1620 is a room-lighting controller for daylight-controlled light regulation, movement-controlled switching, and manual dimming via switches or IR remote control. A maximum of three movement detectors, three infrared receivers and one light cell can be connected. A push-button unit can be connected too, instead of an IR receiver.

The functions can be set by means of the IRT 1090 remote-programming transmitter, used in conjunction with an appropriate sensor. Up to five independent light groups (channels) can be programmed. The TRIOS DALI controller is accommodated in a surface-mounted housing, to which up to 20 electronic DALI ballasts can be connected (see Fig. 104).

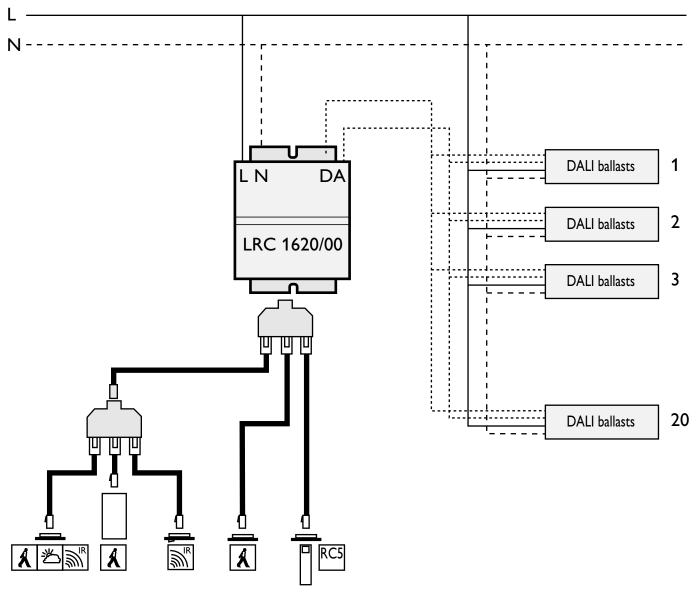


Fig. 104 Wiring diagram: TRIOS DALI.

Although DALI is designed for light management in a single room, its functions can be integrated into a building-management system by means of suitable interfaces.
See also Section 4.2.10

4.3.3 Lighting Management Systems (for complete buildings)

HELIO is a sophisticated lighting-management system. It is a control system for local and building-wide control, an integral part of the building management concept using one network; often integrated with other building services such as heating, ventilation, window blinds, access, etc.
HELIO consists of a network of intelligent components that communicate with each other over a bus. This 'distributed intelligence' eliminates the need for a central controller, thus enhancing system availability. Thanks to its open system architecture, open communications protocol and standardised technology, HELIO can easily be integrated with systems supplied by different vendors.
The whole wide range of devices to generate messages can be used in this system. They send the information to the intelligent controllers via the HELIO bus cable. The controllers deliver the switched mains supply and the DC dimming control signal to the (set of) luminaires.
HELIO controllers can be placed on the ceiling.

HELIO devices fall into three categories: sensor devices (infrared receivers, movement detectors, light sensors, and system clock to transmit status messages onto the bus); actuator devices (light controllers that translate status messages into outputs); and generic network devices (routers, repeaters, bus-power supply units, PC-bus interface cards, and bus cables to manage and transport the bus messages).

Several application software packages are available for a wide range of lighting functions, including:

- **Manual light control**
  Manual and central light control based on inputs from infrared remote control, intelligent wall switches and graphical user interface commands given by the operator.
- **Energy saving and/or energy management**
  Automatic light control based on inputs of movement detectors, light sensors and system clocks with programmable control schedules. Monitoring the actual energy consumption is also an option.
- **Facility management**
  Monitoring the buildings' current lighting status, interfacing with other building services such as heating, ventilation and air conditioning (HVAC) and sun blinds, and reconfiguring the lighting installation when working conditions or office layouts change.

The **LM 100** system is mainly used for lighting only, so not for integration into a Building Management System. It is based on the controller LCM for a maximum of nine luminaires or groups, but 100 LCM controllers can be linked to the so-called Area Controller Unit (ACU) – for example, one per floor. More Area Controllers can be linked to the Central Supervisor.

The **WM 8000** system is based on the Lighting Connection Unit (LCU) with six outputs for six luminaires. The LCU has two addressable relays and a switch to control the six luminaires as 3+3 or 2+4.
With the Area Controllers, a virtually unlimited number of luminaires can be controlled via the Central Supervisor. The maximum number of different channels is 256.

For an extensive description of the various systems, please refer to the Lighting Controls Systems information from the Business Group Luminaires of Philips Lighting.

4.3.4 General-purpose products

There is a wide range of general-purpose products such as dimmers, transmitters, receivers, sensors, push-button interfaces, manual potentiometers, movement detectors, clocks and related cabling for interlinking. It should be noted that not all combinations are always possible, and the correct devices should be employed in the various control systems.

4.3.5 Abbreviations

LPS	light potentiometer
LRD	light regulator (dimmer)
LRI	multi sensor
LRL	light sensor
LRM	movement detector
LLC	luminaire-based controller
LRC	light controller
LRH	Luxsense clip
LCN	Helio router/repeater / PC card
LCU	push-button interface / Helio clock / Helio digital I/O unit
LCS	Helio software
LCC	sensor cable (interlink /extension) / bus cable / connection block
IRC	infrared transmitter
IRT	infrared transmitter
IRR	infrared receiver
SLS	sensor luminaire (Helio)

4.3.6 Installation aspects

1. Study product data sheets, installation instructions, and specification guides and/or handbooks carefully before designing and applying one of the various control systems.
2. Check carefully the needs, wishes and expectations of the customers and users with the possibilities of the preferred or applied control system.
3. Ensure that sufficient knowledge of the control system is available on the side of the contractor. Education possibilities should be available.
4. Mark cabling at beginning and end. Use the correct cabling within the maximum lengths.
5. Avoid humidity and temperature shocks for the electronic components during installation.
6. Connect dimlines according polarity: plus to plus and minus to minus.
7. Treat dimline wiring like mains voltage wiring.
8. Check that the working of the lighting installation is 100 per cent correct before connecting or commissioning the control system. Let the installation run for 24 hours before commissioning.
9. Be careful during the insulation tests (when using megohmmeter).
10. Carefully check the wiring and connections of the control part before starting with the configuration / commissioning.
11. Avoid excessive airflow and temperature changes in the neighbourhood of movement detectors (air-conditioning, fax machines, copiers).
12. Make proper earth connections for the metal optics.

4.4 Electronic ballasts for DC supply voltages

4.4.1 Introduction

DC supply voltages for lighting purposes are restricted to very specific application fields. They can be found in:
- emergency lighting systems, where in the case of a mains supply failure the supply is taken over by stored batteries
- public transport vehicles, such as on board ships, trains, trams, buses, aircraft
- small (portable) domestic items, including torches and inspection lights

Electronic ballasts for these applications have different specifications to fulfil the different requirements. Also, there is a wide spread in the nominal voltage levels: some practical values are: 12, 24, 72 and 110 V and higher. For this reason there are many different types of electronic ballasts for DC supply voltages for fluorescent lamps. This Application Guide will only deal with the two product families that are currently described in the product data sheets.

1. The standard and regulating HF ballast, which can also function on DC for emergency lighting with ‘TL’ or PL lamps.

2a. The emergency control gear EM-M for use with electromagnetic ballasts.

2b. The emergency control gear EM-E for use with electronic ballasts.

2c. The emergency control gear HF-RiEM/DALI for ‘TL’5 lamps.

4.4.2 Special lamps

The combination of fluorescent lamps and DC supplies was already in use before the introduction of the electronic DC ballasts.
Fluorescent lamps of special construction and using special gear can be operated on DC supplies of approx. 70 V and above. The main difference between AC and DC operation is that with the latter an ohmic resistor instead of a choke has to be used as a ballast, although a choke is sometimes added to the circuit to provide a starting pulse when the lamp is switched on (see Fig. 105).
Tungsten filament lamps (either conventional or specially designed types), with their strong positive temperature coefficient of resistance, are almost universally used as current-limiting devices for fluorescent lamps operated on DC.

For supply voltages not exceeding 100 V the electrodes are sometimes preheated. Generally speaking, however, DC lamps are of the cold-start type. To facilitate ignition, auxiliary electrodes in the form of internal conductive strips are normally employed. Two strips are always needed, one connected to each main electrode, for the strip can only serve as the anode. If the supply voltage is higher than 200 V, two or more lamps are often connected in series and started one after the other using an electric relay (see Fig.106).

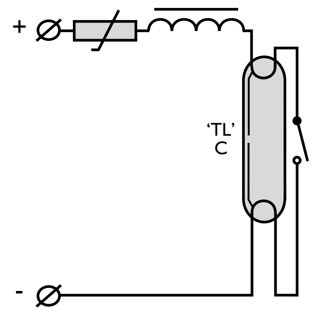


Fig. 105 Schematic diagram for operation of a fluorescent lamp with heated electrodes on 70 V - 100 V DC. The choke provides the starting pulse.

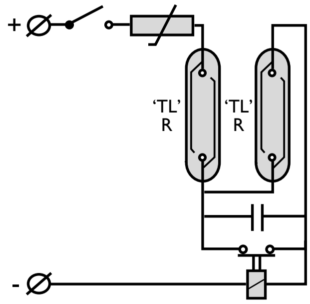


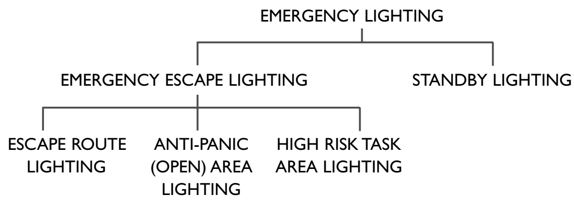
Fig. 106 Twin-lamp sequence-start circuit for operation on 220 V DC.

A typical problem, which only arises with DC operation, is that of **electro-phoresis**. During operation, the mercury in the discharge migrates from the positive to the negative electrode. The result is that a dark zone spreads from the positive electrode, which produces a rapid fall-off in light output. To prevent this from happening, the polarity of the lamp must be reversed at regular periods, e.g. every four hours.

After the introduction of the HF ballasts for DC supplies, the systems described above became less popular.

4.4.3 Emergency lighting: definitions and standards

Emergency lighting is lighting that is designed to come into operation when the normal lighting fails. It is split up into the segments shown:



Standby lighting is defined as that part of the emergency lighting system that enables normal activities to continue or to be terminated safely, e.g. lighting in the control room of a petrochemical factory to enable the operator to shut down the process safely. It depends very much on what normal activities are taking place as to the requirements that have to be set for good standby lighting, so there are no general standards for this segment. **Emergency escape lighting** is defined as that part of the emergency lighting that provides illumination for the safety of people leaving an area or attempting to terminate a dangerous process before vacating an area. Harmonised European standards have been developed, or are in development, for the three parts:

- **Escape**-route lighting is defined as that part of the emergency escape lighting that is provided to ensure that the means of escape can be effectively and safely used when the building is occupied.
- **Anti-panic** (open) area lighting is defined as that part of the emergency escape lighting that is provided to avoid panic and provide illumination to allow people to reach a place where an escape route can be identified.
- **High-risk** task-area lighting is defined as that part of the emergency escape lighting that provides illumination for the safety of people involved in a potentially dangerous process or situation, and that enables proper shut-down procedures to be completed for the safety of the operator and other occupants of the premises. Standby lighting can also function as high-risk task area lighting.

The European standards and recommendations cover the following aspects: minimum illuminance, uniformity (min/max), response time, duration, colour rendering, luminous intensity, and siting of luminaires and safety signs.

Standards in emergengy lighting

Requirements	**Escape route lighting**	**Anti-panic (open) area lighting**	**High-risk task area lighting**
Illuminance	> 0.5 lux (unobstructed route) > 1.0 lux (obstructed route)	> 0.5 lux	10 % of normal and > 15 lux
Response time (50 %)	< 5 sec.	< 5 sec.	
Response time (100 %)	< 15 sec.	< 15 sec.	< 0.25 sec.
Duration	> 1 hour	> 1 hour	duration of risk
Colour rendering index	Ra > 40	Ra > 40	Ra > 40
Uniformity (min./max.)	> 0.025	> 0.025	> 0.1

There are basically two types of emergency lighting systems:

1) **Maintained** emergency lighting, in which all emergency lamps are in operation at all times when normal or emergency lighting is required.
2) **Non-maintained** emergency lighting, in which all the emergency lighting lamps are in operation only when the supply to the normal lighting fails.

Luminaires can be divided into:

- **Centrally supplied** emergency luminaires for maintained or non-maintained operation. These are energised from a central emergency power system not contained within the luminaire.
- **Self-contained** emergency luminaires for maintained or non-maintained operation. Here all the elements, such as battery, lamp, control unit and test and monitoring facilities, where provided, are contained inside the luminaire or at a distance of not more than 1 m from it **(decentralised)**.

- **Combined** emergency luminaires, which contain at least two lamps, at least one of which is energised from the emergency lighting supply and the other from the normal lighting supply. A combined emergency luminaire is either maintained or non-maintained.

Recommendations and standards for decentralised emergency lighting state minimum lighting levels and minimum burning times, but no voltage restrictions. For central emergency lighting, however, there are various regulations, which differ from country to country. Commonly used are the EN 60598-2-22 and VDE 0108.
- stable burning must be realised for a mains voltage range from 0.80 V_{nom} to 1.15 V_{nom}.
- ignition and re-ignition must be possible between 0.90 V_{nom} and 1.15 V_{nom}.

A second requirement for emergency lighting is that the switch-over time from normal to emergency operation or back is limited, depending on the nature of the space (room) and the activities in that room. For high-risk task area lighting a maximum response time of 0.25 seconds is prescribed in the harmonised European standards.
For escape-route lighting and anti-panic area lighting the response time must be less than 5 seconds.

The decentralised system is the most reliable, as the individual lamps can go on functioning even during a fire or when the mains cable is destroyed.

4.4.4 Emergency lighting systems

Central

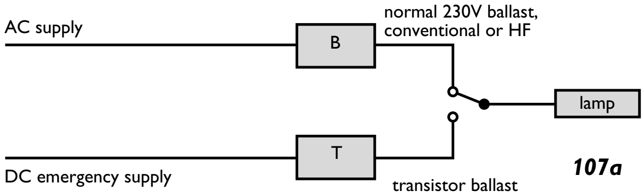
1. See Fig. 107a. Here the normal and emergency supplies and circuitry are separated and the lamp connections are switched by the change-over switch in the luminaire. The normal circuit can contain conventional or HF ballasts; the emergency circuit can have special ballasts. There is no special Philips solution.

2. See Fig. 107b. Here there is a central change-over switch and the luminaire contains only the normal HF ballast circuit. This circuit is the least safe of all circuits, but also the cheapest one.

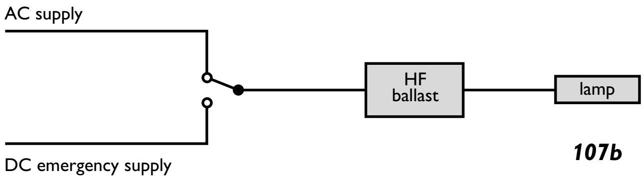
Decentralised

3. See Fig. 107c. Here the lamp is continuously being powered by an HF converter, which receives energy via the normal mains supply or from the continuously-loaded battery pack. Should the mains power fail, the battery can supply the energy necessary for the required time of operation. The HF converter can be a special DC low-voltage ballast.
   In normal operation the lamp usually has to deliver 100 per cent light output all the time. Therefore the transformer in the charge unit becomes rather large for higher wattage lamps. This is the reason that this circuit is not widely used for permanent (maintained) lighting.
   But this system can be used for non-maintained operation: the lamp only functions for the specified time when the mains supply fails. This is possible with the EM-M and EM-E emergency control unit (see Fig. 108).

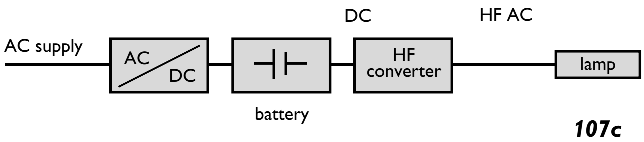
Fig. 107 Principles of various systems of decentralised and central emergency lighting provisions.



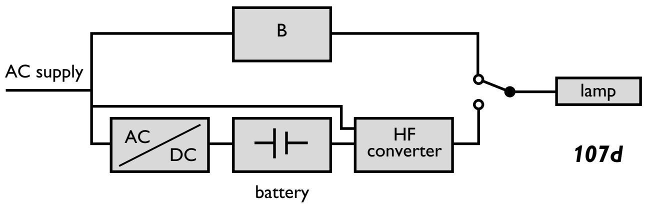
107a



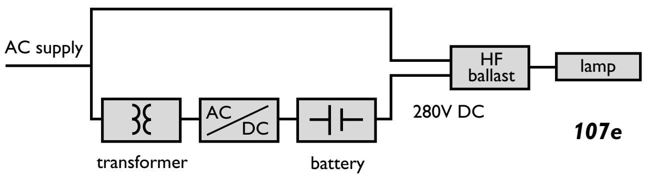
107b



107c



107d



107e

Fig. 107a Normal and emergency supplies and circuitry are separated; change-over switch in the luminaire.

Fig.107b With central change-over switch and one HF ballast.

Fig. 107c Lamp powered by an HF converter, receiving energy from a battery pack.

Fig. 107d Emergency circuit parallel to the mains circuit.

Fig. 107e Standard HF ballast used in combination with a transformer, charger and battery.

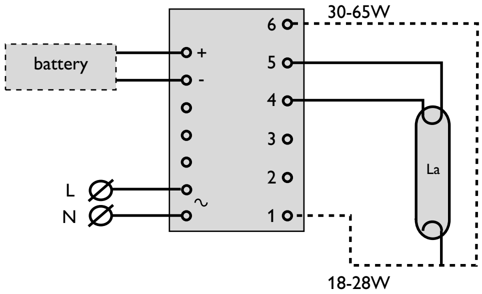


Fig. 108 Wiring diagram: emergency control non-maintained.

4. See Fig. 107d. Here the emergency circuit is connected in parallel to the normal mains voltage circuit. This is the most widely used system. By means of a change-over switch in the luminaire the lamp is powered either by the emergency circuit or by the mains supply circuit (maintained), see Fig. 109.
   In the emergency situation the lamp can be powered by less energy than in the normal situation, indicated by the so-called ballast lumen factor. The ballast lumen factor is the ratio of the luminous flux from the lamp when operated on the emergency ballast to that produced on the reference ballast. The percentage depends greatly on the type of lamp and batteries used. For example, see table below for the EM-M controllers, suitable with electromagnetic gear.

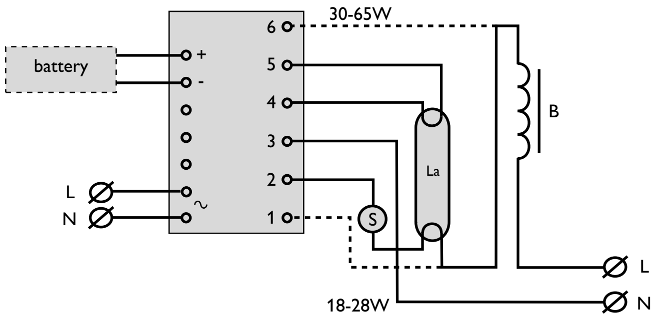


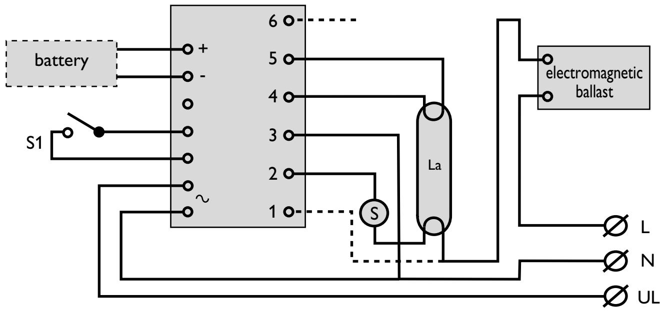
Fig. 109 Wiring diagram: emergency control maintained.

Ballast Lumen Factors* *(Indicative)*

Lamp type	**Luminous flux: 1-hour supply EM-M 065-01/04**	**Luminous flux: 3-hour supply EM-M 065-03/05**
'TL'D 18 W	35 %	30 %
'TL'D 36 W	20 %	15 %
'TL'D 38 W	25 %	20 %
'TL'D 58 W	15 %	10 %
'TL' 20 W	40 %	35 %
'TL' 40 W	20 %	20 %
'TL' 65 W	10 %	10 %
PL-L 18 W	40 %	30 %
PL-L 24 W	30 %	20 %
PL-L 36 W	20 %	15 %
PL-C 18 W	40 %	30 %
PL-C 26 W	30 %	20 %
PL-T 18 W	40 %	30 %
PL-T 26 W	25 %	20 %

* Ballast Lumen Factor: ratio between luminous flux from lamp when operated on emergengy ballast and reference ballast.

The EM-E controller can also be used in this system in combination with HF ballasts (see Fig. 110 for EM-M and Fig. 111 for EM-E). In both EM-E and EM-M controllers the functions AC/DC, battery, HF converter and change-over switch are integrated.



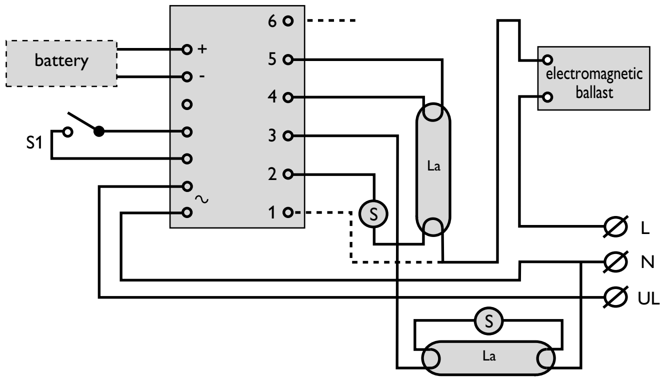


Fig. 110 Wiring diagram: emergency control unit EM-M, 1 and 2 lamps.

5. See Fig. 107e. Here the standard HF ballast is used in combination with a transformer, charger and battery. Due to the high DC voltage, necessary for the HF ballast (typically 280 V), this system is rarely used. The RiEM-DALI controller is more or less like this system, as it contains all functions (transformer, AC/DC, battery, HF ballast and change-over switch).

Restrictions for switching

Switching over from the normal situation to the emergency situation normally causes no problems. When switching back from emergency to normal operation, care should be taken for the proper ignition of the lamp. In the case of conventional ballast circuits it is not allowed to employ glow-switch starters (see IEC 60598-2-22.6-1), so electronic starters are to be used. These starters have, like the HF ballasts, predefined ignition characteristics. In order to ensure reliable ignition, the change-over switch has to fulfil certain restrictions.

From Figs 107a to 107e we can distinguish three different types of switching:

- Switching the input voltage of the HF ballast from AC to DC or vice versa (Figs 107b and 107e).

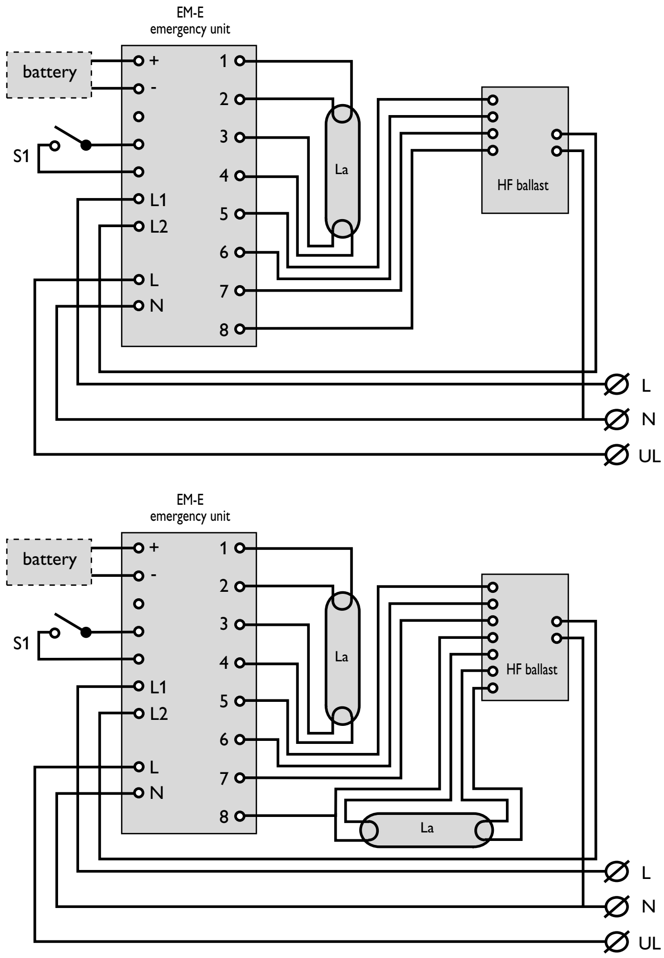


Fig. 111 Wiring diagram: emergency control unit EM-E, 1 and 2 lamps.

If there is no input voltage for more than a few milliseconds (10 to 35 ms, depending on the ballast type), the ballasts are reset and the lamps extinguish. This means that the lamps have to start again when the input voltage is restored. If the change-over switch reacts within these few milliseconds, the lamps continue burning. But in most cases the switch-over time is longer and then the warm start ballasts cannot fulfil the requirement of the maximum switch-over time of 0.25 s (if necessary).
As the contacts of the switch or relays have to be suitable for a DC voltage of 300 V and for the inrush currents, special switch gear is necessary.

- Restoring the mains supply after an emergency or after the emergency test procedure (Figs 107a and 107d). The lamps will only burn on the AC supply when the switch-over switch is in the up position. If it is not in that position, the HF ballast or electronic starter will 'see' no lamp and so the ignition process will stop after a few seconds. It will restart again when the change-over switch is put in the up position. To avoid possible ignition problems, it is recommended to let the lamp function on the emergency circuit for at least 3 seconds after the restoration of the mains supply before switching to the AC circuit.

- Lamp change-over from emergency to normal AC circuit and vice versa.
  Switching the lamp from one circuit to the other can be done by switching all the lamp terminals with a 4-pole relay.
  The circuit diagram depends on the converter and ballast used. Due to the great variation in converter and ballast circuits, no general circuit diagram can be given. In case a certain converter has to be combined with a Philips ballast, the local Philips sales organisation can provide the optimum circuit diagram on request.

4.4.5 The standard and regulating HF ballast with standard lamps

The Philips HF ballast can be used on a DC voltage for emergency lighting, although only for relatively short periods. This is possible because it contains a diode bridge circuit, which transforms the customary AC voltage into a DC voltage. The buffer capacitor of the ballast ensures that the rectified voltage is higher than the r.m.s. value of the AC voltage from the mains (280 V instead of 230 V). This means that the older types of HF ballast must be operated with a 280 V DC voltage if the lamp is to provide the same luminous flux as that obtained with 230 V AC. However, if the ballast is operated on a DC voltage of, for example, 220 V, the luminous flux will be approx. 20 per cent lower.
The newer types of HF ballasts contain an up-converter giving 100 per cent light output at 230 V DC.
The third-harmonic ripple in the supply voltage should be limited to < 1.5 %.
As the lamp side of the ballast is functioning similar to the normal AC operation, all lamp-related information of Sections 4.1 and 4.2 is applicable, but the normal lifetime and failure rate of the gear cannot be guaranteed by continuous operation on DC. Especially low DC voltages (<198V) can influence the lifetime of the ballast.
For a continuous DC application, an external fuse should be used in the luminaire.

For the HF ballast a DC voltage range is specified.
From the table below it can be seen that for a nominal emergency supply voltage of approx. 220 V the requirements can be fulfilled.
For universal use, the lamps have to be (re-)ignited within 0.25 seconds of applying the restored mains voltage. This is not possible with the warm-start versions HF-P and HF-R.

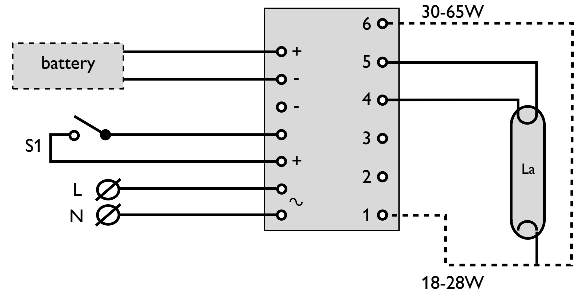
Various HF ballasts with their DC voltage range and re-ignition time

HF ballast	Voltage range DC (V)		Ignition < 0.25 sec
	Guaranteed ignition	Stable burning	
HF-B	198-254	176-254	Yes
HF-R	198-254	176-254	No
Most HF-P	198-254	176-254	No
HF-P TL5C	196-276	176-276	
One lamp:			
HF-P PLL18/24	154-276	154-276	No
HF-P PL-T/PLC			

All ballasts start within 2 seconds and can be employed in less critical applications.

4.4.6 Products – Emergency control gear

The components EM-E and EM-M are designed for use in decentralised systems only. They include a battery charge and discharge control with LED signalling and mains-failure detection. The wiring is simple: with a separate ballast the products are suitable for maintained operation and without a separate ballast for non-maintained operation. In the 'emergency' mode (mains power off) the unit can be switched off by means of the control input.
This can be realised by a switching contact or a DC voltage of 3....15 V, see Fig. 112 (a pulse contact or voltage with duration more than 0.1 second is sufficient). In this way the battery will not be uncharged in cases where the mains supply is off, but there is no emergency situation. Switching-in can be done by restoring the mains supply. The maximum cable length between unit and lamp is restricted to 1.5 metres.



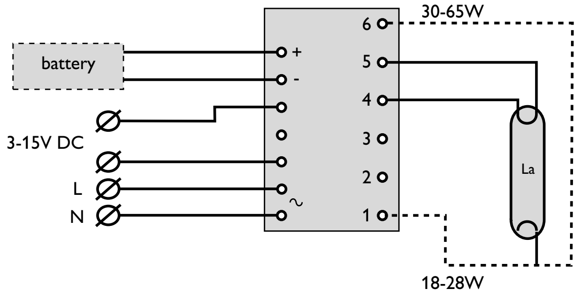


Fig. 112 Saving battery by extra switch or DC voltage.

The HF-RiEM DALI converter is an intelligent micro-processor-controlled emergency unit with integrated ballast for one TL5 fluorescent lamp of 14, 28, 35 or 49 W, see Fig. 113. By means of the DALI protocol these can be dimmed down to give a minimum of 3 per cent of normal light level. The converter includes the function of an automatic emergency system check (programmable per day, week or quarter) for ballast, lamp and battery performance. The various system failures are displayed by the blinking LED, with for each fault a different sequence.

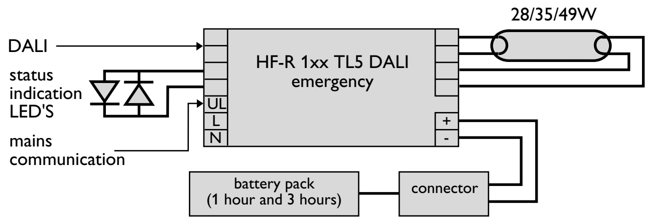


Fig. 113 The HF-RiEM DALI emergency unit.

4.4.7 Battery information

After four years of use, the battery capacitance has to be sufficient to fulfil the requirements of 1 or 3 hours running after a mains switch off.
Parameters that influence the capacity are:
- magnitude of the battery charge current
- magnitude of the battery discharge current
- total number of test/discharge cycles
- ambient temperature in charge and discharge mode

Batteries are supplied in the uncharged condition. Before using the emergency mode, it is necessary to charge the battery pack for at least 24 hours to fulfil the 1- or 3-hour requirement. Mark the date label on the battery packs before using.
Store batteries in a dry location with low humidity, where no corrosive gases are present, and at a temperature of between -20 °C and +45 °C.
The battery packs have to be of a high temperature type, see Fig. 114 which gives the capacity decrease of the battery as function of the temperature.

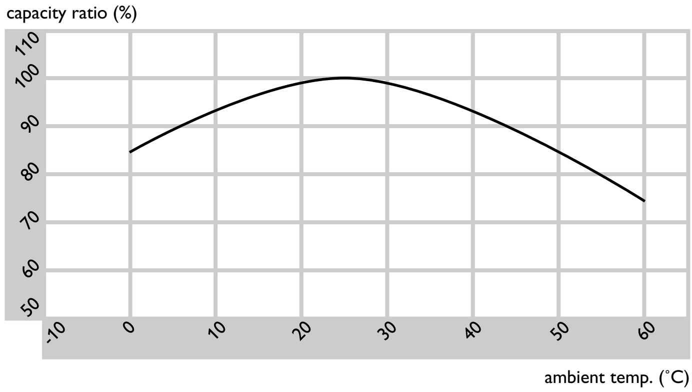


Fig. 114 Battery capacity ratio as function of the temperature.

4.5 The fluorescent induction lamp system (QL)

4.5.1 Preface

The QL lamp system represents a totally new concept of light generation based on the principles of induction and gas discharge. This distinctive lamp system therefore has to be classified in a separate family of sources, the so-called QL induction lighting systems.
Although the light emission in the lamp is still based on the gas-discharge principle, the ionisation itself occurs without the use of electrodes. This provides the QL lamp system with an extremely long life in the order of 60 000 hours. It offers possibilities in lighting systems for applications that until now were impractical or uneconomical because of excessive maintenance requirements or in those applications where the lighting is used intensively.
QL systems are primarily meant to be fully integrated into luminaire/lighting systems.
Special information for luminaire manufacturers is available from Philips Lighting sales organisations (publication no. 3222 635 21921, dated 12/99).

4.5.2 Introduction (see Fig. 115)

Induction lighting is based on the well-known principles of induction and light generation by way of a gas discharge. Induction is the transportation of energy using an electromagnetic field. A practical example is a transformer, which consists of an iron or ferrite core with a primary and a secondary coil (or ring, see Fig. 115a).
An alternating current Ip through the primary coil (Fig. 115b) induces an alternating electromagnetic field in the ferrite core and the space around that core. This alternating field in turn induces an alternating secondary current in the secondary coil or ring (I_s).
The higher the frequency of the alternating current, the higher the efficiency of the system.
In an induction lamp system the (metal) vapour or gas can be seen as forming the secondary coil or ring (Fig. 115c). This means that the induced current (I_s) circulates through the metal vapour or gas, causing the acceleration of free electrons, which collide with the vapour or gas atoms and bring electrons to a higher level (energy state). Electrons from excited atoms fall back from this higher energy state to the lower stable level and consequently emit ultraviolet photons. The UV photons interact with the fluorescent powder on the wall of the discharge vessel, whereby visible light is generated.

4.5.3 General construction and working principle

The QL lamp system consists of three mutually dependent main components (Fig. 116).
A: The lamp (discharge vessel)
B: The power coupler (construction base with antenna, heat sink and electrical connection cable)
C: The HF generator (electronics including housing)

Fig. 115 Working principle of the fluorescent induction lamp.

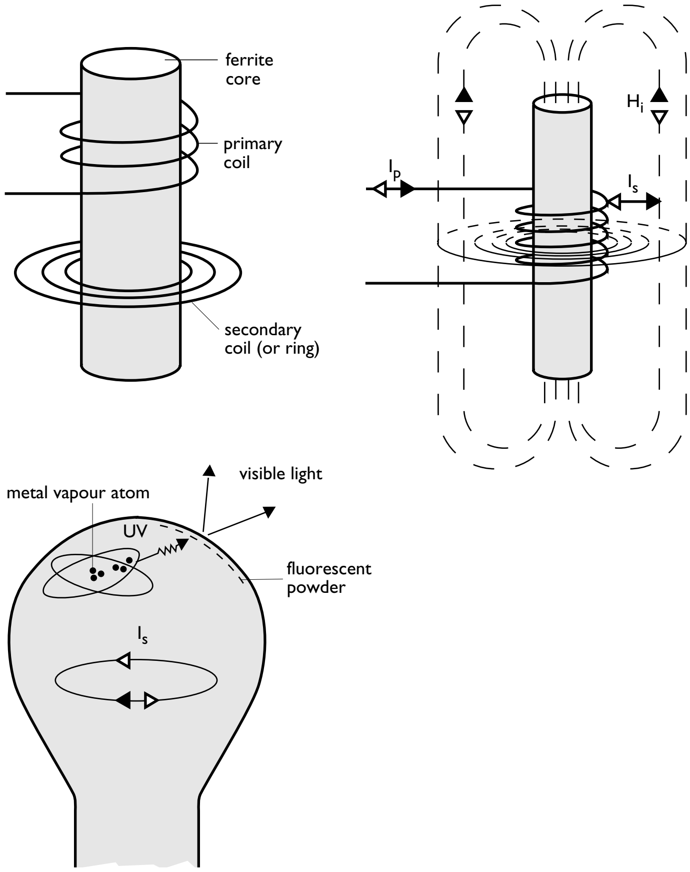


Fig. 115a and Fig. 115b Induction principle.

Fig. 115c Discharge principle.

The QL discharge vessel is basically a glass bulb containing a low-pressure mercury vapour (Fig. 117). The walls are coated on the inside with a fluorescent powder of any of the modern three-line phosphor types. At the present time, the colours /827 (2700 K), /830 (3000 K) and /840 (4000 K) are available.

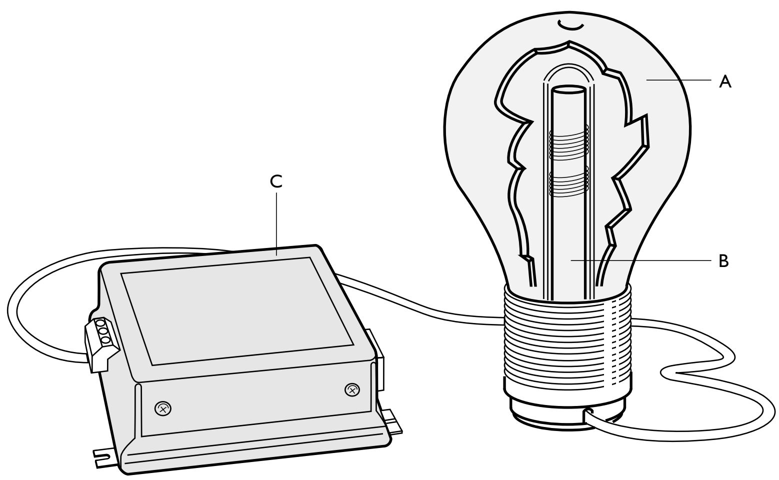


Fig. 116 General view of the QL lamp system.

The discharge in the vessel is supplied by means of an alternating electromagnetic field (induction) generated by an antenna (induction coil) – thus without the help of electrodes. The cylindrical antenna, which forms part of the so-called power coupler, is located in a cavity inside the discharge vessel.
A mercury amalgam mixture, housed in a reservoir attached to the discharge vessel, helps maintain the light output at a more or less constant level over a large temperature range. To ensure a short run-up time, use is made of a so-called auxiliary amalgam positioned close to the discharge.
The glass bulb is fixed to the bottom part of the power coupler by means of the plastics lamp base (Fig. 118).

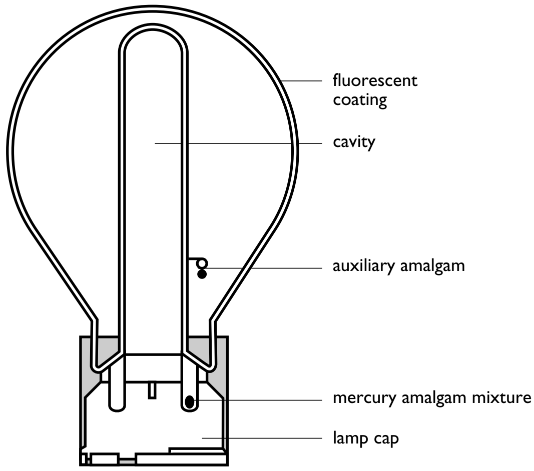


Fig. 117 The discharge vessel.

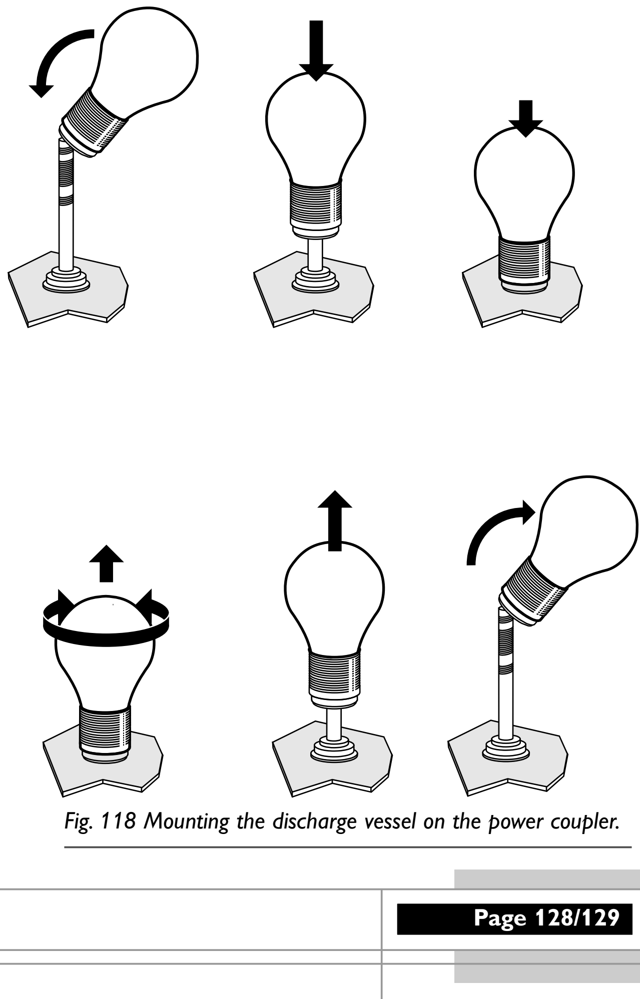


Fig. 118 Mounting the discharge vessel on the power coupler.

These two parts need to be assembled only once during the construction of the system and, due to their very long life, need normally never be disassembled.
The power coupler (Fig. 119) is that part of the QL lamp system that transfers the energy from the HF generator to the discharge. It consists of a plastics support, housing the antenna, a coaxial connecting cable, and a heat conductor with mounting flange.
The antenna, which is located in a cavity in the centre of the discharge vessel, includes a coil and a ferrite core, which produce a high-frequency electromagnetic field (2.65 MHz +/- 10 %).

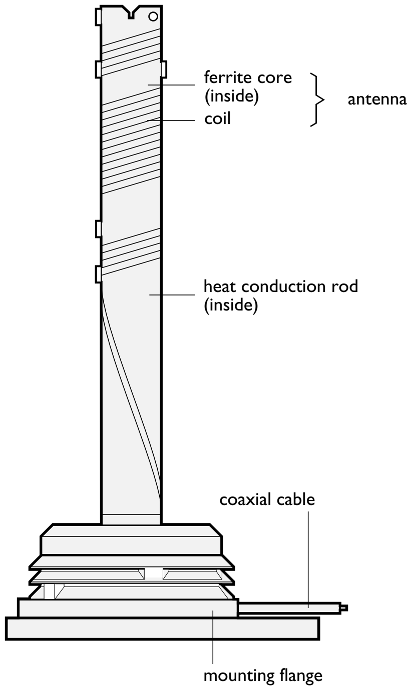


Fig. 119 Power coupler.

The alternating electromagnetic field provides the energy to the gas discharge inside the discharge vessel. The redundant heat produced by the coil and the discharge is removed to the mounting flange by means of a conducting rod, which is located inside the antenna.
The mounting flange also ensures the mechanical connection between the lamp and the luminaire. The fixation is by means of screws.
The electrical connection between the antenna and the HF generator is formed by a shielded coaxial cable. It is permanently fixed on the antenna side but can be (dis-) connected on the side of the HF generator by means of a screw connector to facilitate mounting of the lamp system in the luminaire. The length of the cable is about 400 mm. Since the cable forms part of the oscillator circuit, its length may not be changed.
The HF generator consists of an oscillator, which supplies the high-frequency power to the antenna to initiate and maintain a gas discharge in the glass vessel. It also acts as a pre-conditioner, taking care of the oscillator power supply and filtering in the direction of the mains. In addition, it provides a very good power factor and a low harmonic distortion of the mains.

All the electronics are housed in a metal box with a dual function to ensure proper functioning of the electronics: screening against Radio Frequency Interference (RFI) and heat conduction.
If the metal housing and power coupler are properly electrically connected to earth, the system will in principle satisfy all (inter)national requirements regarding electromagnetic compatibility.

4.5.4 Steady operation

The high-frequency power signal is generated by the oscillator circuit at a frequency of 2.65 MHz. This frequency not only guarantees the most efficient power coupling to the discharge vessel, but also has the advantage of not being occupied by normal broadcast bands, which reduces the risk of radio interference.
For the same reason, meticulous care has been taken to generate a pure sine wave, as this waveform contains no harmonics, which would give rise to difficult-to-suppress high-frequency interference signals.
The UV-radiation level of QL lamps is not higher than that of any 80-series fluorescent lamp.
Apart from visible light, the QL lamp system emits a certain amount of invisible infrared radiation. This radiation is modulated with the frequency of the lamp current (2.65 MHz). This means that IR interference is extremely low – lower even than with other HF fluorescent lamp systems.

4.5.5 Ignition and run-up

For fast and reliable starting, a high-voltage (>1500 V) and short (100 ms) ignition pulse is sent through the antenna coil. The ignition pulse is powerful enough to also ensure reliable hot restrike of the lamp after a power interruption.
The ignition pulse first initiates a capacitive glow discharge near the wall of the power coupler cavity in a similar way to that produced by the external conductive strip or wire along the discharge tube that is used as a starting aid in several other lamp types. The glow discharge generates sufficient free electrons by ionisation to release the main arc discharge, which is sustained by inductive power coupling.
The discharge of the QL induction lamp system is of the low-pressure type. This means that the luminous flux is dependent on the density of the metal atoms in the gas filling. This density is related to the vapour pressure, which in turn is controlled by the temperature of the coldest spot of the discharge vessel.
The run-up process from a completely cooled-down system is characterised by a steady increase of the temperature inside the discharge vessel. However, if nothing were done to speed it up, the corresponding increase of the light output would be a slow process. This is because the main amalgam (the vapour pressure and light output controller) is located at a remote cool spot far from the centre of the discharge, in one of the exhaust tubes at the bottom. An auxiliary amalgam is therefore employed, which is found on the wall of the cavity that houses the power coupler, a spot that most quickly gains temperature during the run-up period, see Fig 120.

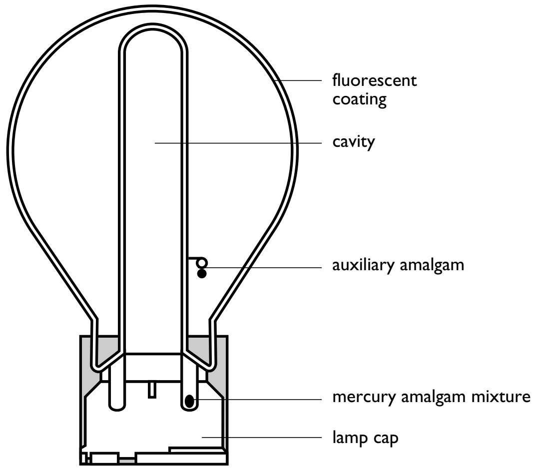


Fig. 120 A capacitive glow discharge precedes the main arc discharge.

After ignition, the auxiliary amalgam heats up very quickly and starts releasing mercury. From this moment on, during the following run-up period, the temperature of the bulb wall determines the mercury vapour pressure, just as in a normal fluorescent lamp. If a QL lamp system is switched on after a complete cool-down, the light output will very rapidly (within 10-15 seconds) increase to about the stabilised level.
The increasing temperature in the discharge vessel heats up the main amalgam, which slowly starts to control the final mercury pressure. The complete run-up process – although scarcely noticeable in terms of light output – takes well over one hour (see Fig. 121).
The ignition time of the system is less than 0.1 second.
The hot-restrike time is also less than 0.1 second.
The minimum ambient temperature for ignition is -20 °C.

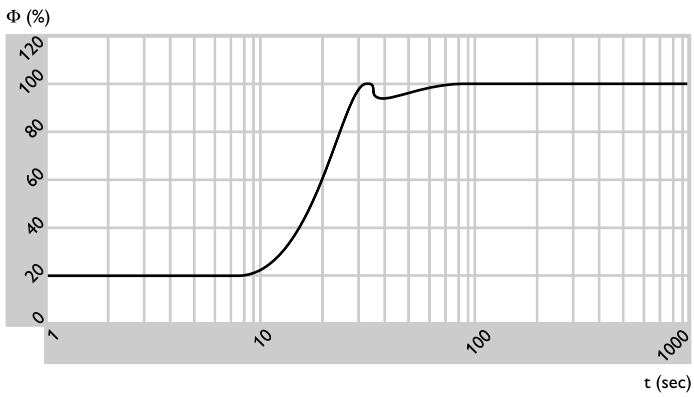


Fig. 121 Relative light output during run-up.

4.5.6 Luminous efficacy

At present, the system efficacy of QL fluorescent induction lamps is 65, 70 or 73 lm/W at a power of 55, 85 or 165 W. By comparison, the system efficacy of integrated compact fluorescent lamp types (SL and PL*Electronic) varies between 40 and 65 lm/W.

4.5.7 Energy balance and influence of ambient temperature

Fig. 122 shows the energy balance of the 85 W QL lamp system. It appears that 17 per cent of the input power is converted into visible and (very little) UV radiation, the rest being 'lost' in the form of heat. Part of the heat is generated in the induction coil of the power coupler, where the temperature can rise to as high as 250 °C. Lamp performance in terms of luminous flux, however, is principally determined by the temperature of the main amalgam, which is located in one of the exhaust tubes at the bottom of the bulb. Adequate lamp performance, that is to say a luminous flux of more than 85 per cent of the nominal value, is obtained if the temperature of the main amalgam is maintained within the range of 50 °C to 105 °C (see Fig. 123). The amalgam temperature is influenced by the outside ambient temperature, the burning position, and the thermal insulation properties of the luminaire.

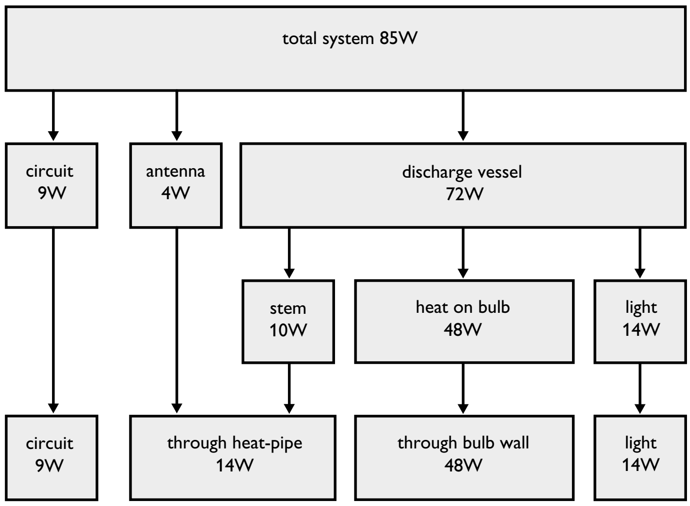


Fig. 122 Energy balance of an 85 W QL lamp system. Heat losses 9 + 14 + 48 W = 71 W, and 14 W light power.

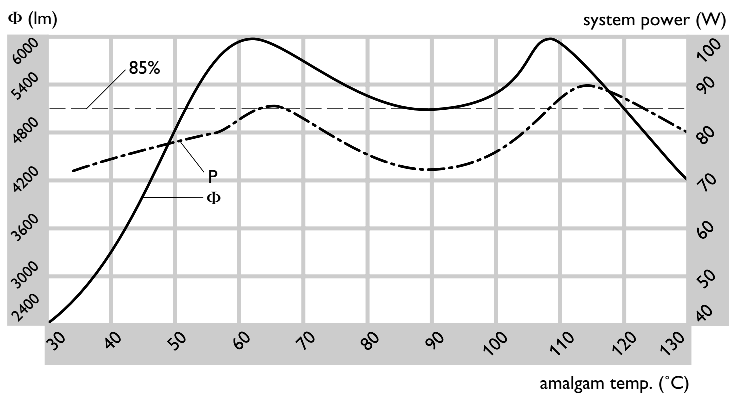


Fig. 123 Curves showing the relationship between amalgam temperature and dissipated power and luminous flux, respectively, for an 85 W QL system.

Though it is an efficient light source, still a lot of heat is created at the bulb wall from where it is subsequently removed by convection and radiation. The generated power on the outer part of the bulb gives rise to a temperature exceeding the ambient temperature by nearly 100 °C. The coolest spots of the discharge vessel are the exhaust tubes located in the base. But even these can reach a temperature of up to 100 °C.
The temperature of the inner glass part of the bulb (stem) is much higher than the temperature of both the exhaust tube and the bulb wall.

4.5.8 Stray radiation and radio interference

Because the QL lamp system makes use of a relatively high operating frequency compared to conventional light sources, the electromagnetic radiation has been investigated extensively with regard to interference with the environment and hazardous radiation.
The system in itself will fulfil all standards relating to Electro-Magnetic Compatibility (EMC Class A for the 165 W and Class A&B for the 55 and 85 W types).
To ensure that electrical or electronic systems will not cause unacceptable interference with the environment, regulations have been laid down that set limits to the emitted interference (see Section 2.3).

4.5.9 Lamp life and depreciation

At present, the indicated life expectancy of a QL lamp system is 60 000 hours, (or almost fifteen years of continuous operation, based on 4000 burning hours per year and 10 % failures). For practical reasons, this value is not based purely upon tests carried out on a large number of lamps under rated conditions, but also on calculations on the basis of known data on the depreciation rate of the phosphors used and the statistical failure chance of the individual electronic components.
The assumption that a light output depreciation of 30 per cent is the maximum acceptable value for economic operation resulted in a lifetime of 60 000 operating hours. The corresponding expected failure rate is less than 10 per cent.
Lifetime measurements on QL systems and their performance in actual practice support these figures. Moreover, the QL design is such that in the case of an early failure, only the defective part needs to be replaced.

4.5.10 Electrical aspects

Like in the standard HF frequency system, the following electrical functions can be found (see Fig. 124):
- radio interference filter,
- AC/DC converter,
- buffer capacitor,
- high-frequency oscillator,
- stabilisation coil L1.

The power coupler with its coaxial cable forms part of the 2.65 MHz oscillator. Therefore, in order not to disturb the resonance circuits, the length of the coaxial cable should not be made any longer or shorter. The coil L2 of the power coupler acts as the primary winding of a transformer. The secondary winding is formed by the discharge current in the vessel.

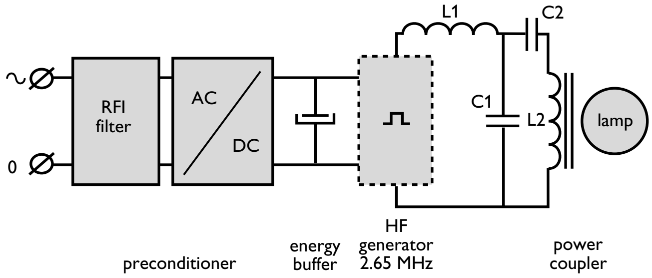


Fig. 124 Electrical circuit diagram of the QL lamp system.

The nominal mains voltage is 230 V / 50 or 60 Hz with a permissible voltage fluctuation from 190 to 255 V. Fig. 125 gives the lamp light output as a function of mains voltage. The power factor is higher than 0.96 capacitive.
The inrush current is maximum 45 A peak with a half-value time less than 350 μs for the 55/85 W version and 45A/500 μs for the 165 W, both 230 V versions (see Fig. 126). With a simple solid-state relay the inrush current can be limited to about 3 to 4 A.

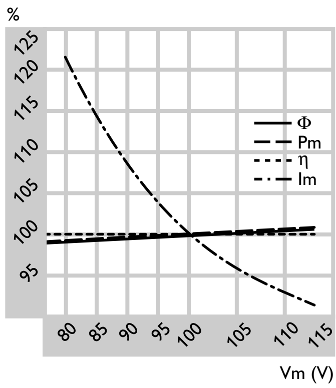


Fig. 125 Influence of mains voltage fluctuations for a QL lamp system.

Typical voltage and current values for QL system

	V_{nom}	Inrush current 1/2 value time at typical mains impedance I_{max} / τ
QL 55W S/03	230V	45A / 350μs
QL 85W S/03	230V	45A / 350μs
QL 165W S/01	230V	45A / 500μs
QL 55W S/13	120V	25A / 550μs
QL 85W S/13	120V	25A / 550μs

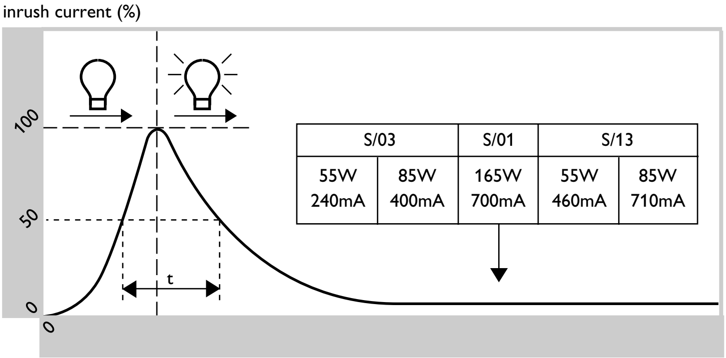


Fig. 126 Inrush current of the QL systems.

The QL system can also operate directly on a DC mains voltage of 220-240 V for nominal light output, and the required battery voltage for guaranteed ignition is from 190 to 264 V. The plus-pole must be connected to the live terminal and the minus-pole to the neutral.
When switching signals are transmitted via the mains, filter coils are recommended (Cin HF generator: 660 nF).
Versions for a mains supply of 120 V 50/60 Hz are available for the QL 55 and 85 W.

4.5.11 Installation aspects

- The coax cable between HF generator and the antenna is carefully chosen to match EMC requirements and to ensure proper functioning. It should never be made any longer or shorter.
- The length of the supply cables close to the discharge vessel and coaxial power coupler cable should be minimised. They should be positioned as far as possible from the discharge vessel. If the distance to the discharge vessel is less than 1 m, an extra earth shielding for the supply cables is advised.
- Never switch the lamp system on with the discharge vessel removed.
- For safety reasons, it is recommended that the metal case of the HF generator be connected to the earth terminal (Class I).
- The HF generator should be mounted in such a way that the maximum permissible case temperature t_c at the test point is less than 65 °C in all circumstances.
- In the case of failure or damage to one of the three main components, the component concerned can be serviced separately.
- In the case of lamp failure or breakage of the bulb, the system will automatically switch off. The situation can be reset by switching off for about 15-30 seconds.
- Although the permissible burning position is universal, there is a difference in the luminous flux between the base-up and base-down position in combination with a specific luminaire design (see Fig. 127).
- The system includes a flicker-free start.
- The system has an over-voltage protection, which can handle a voltage of 320 AV for 48 hours and 350 V for 2 hours.
- See Fig. 128 for survivals and lumen maintenance as function of the burning hours.
- The light output varies with the ambient temperature and cooling properties of the luminaire (see Fig. 129).

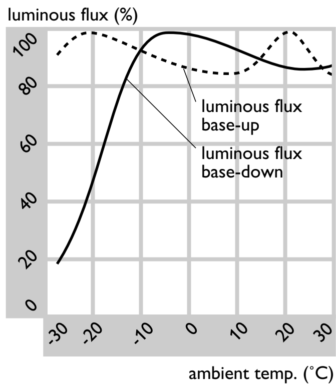


Fig. 127 Influence of the burning position on the light output of a QL lamp.

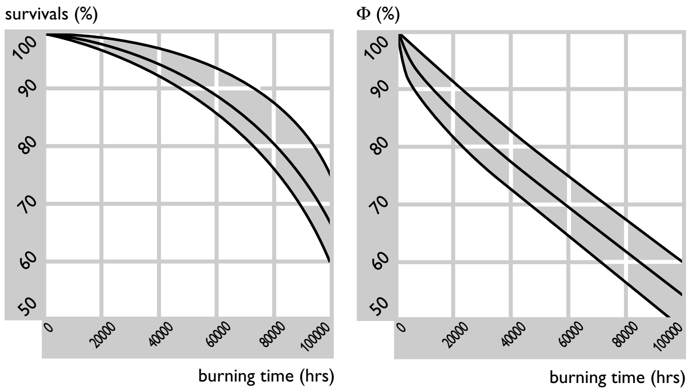


Fig. 128 Survivals and lumen maintenance as function of burning hours.

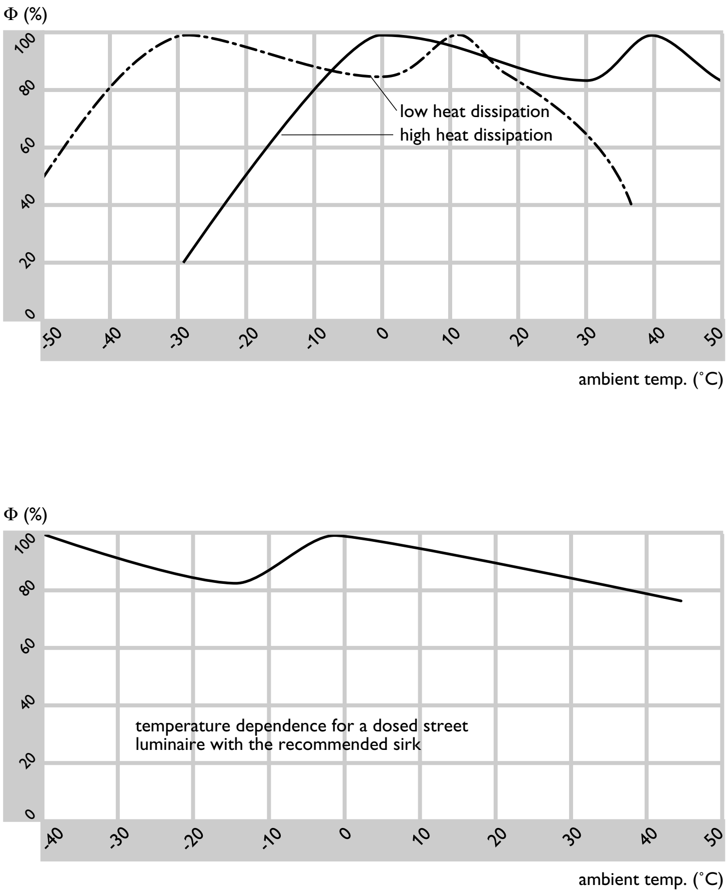


Fig. 129 Light output as function of the ambient temperature and heat dissipation.