



CELMA

C.E.L.M.A.

*Federation of National Manufacturers
Associations for Luminaires and
Electrotechnical Components for
Luminaires in the European Union*

CELMA STATEMENT

Through life costs of an installation comparing the benefits of high frequency control gear with those of magnetic control gear used with low pressure mercury fluorescent lamps

Note: this CELMA Statement is based on the LIF Technical Statement 38

September 2007

EXECUTIVE SUMMARY

High frequency (HF) electronic ballasts have been used in fluorescent lamp lighting fittings for over 20 years. They have been developed to the point where they are now the preferred choice of specifiers and users. This document lays out the features and benefits of the two types of technology and then goes on to carry out a quick comparative calculation of the through life costs of an installation of HF versus magnetic.

There is now a great deal of experience of using HF ballasts in installations and practical evidence of the life curves and actual energy savings achievable.

In the example shown, you will find that the extra initial cost of the HF solution is paid back within the first year and that the through life costs of the HF installation is only 86% of the magnetic. These results are typical.

INTRODUCTION

The aim of this technical statement is to look at the impact of two very different lamp control technologies and compare the economics of electronic controlled gear (herewith referred to as High Frequency or HF gear) to that of Electromagnetic circuits (also known as Chokes). This statement looks at the technical argument for HF gear and discusses product life and operation, highlighting the major benefits of HF technology.

The growth of electronic control gear in general lighting practice has revolutionised the quality of light but also the design construction, and operation of luminaires.

CONSTRUCTION

Electromagnetic

Electromagnetic ballasts (chokes) are used to limit current runaway in low-pressure gas discharge circuits. A choke consists of a large number of copper windings on a bobbin surrounded by a laminated iron core. Often the choke is impregnated with resin to protect the iron laminations and copper from oxidation.

The impedance of each choke must be selected to suit, mains voltage, frequency, lamp type and lamp operating voltage. Ballast impedance is crucial for stabilisation.

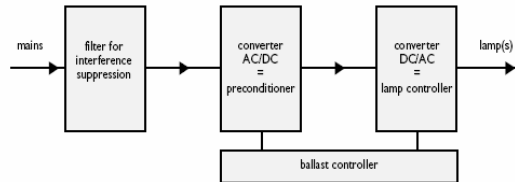
Generally we can state that each choke is specific to a particular lamp wattage and style.

This simple method of construction has some advantages in its simplicity, resistance to higher ambient temperatures and robustness. However, additional components are required to complete the circuit such as a starting device and power factor correction capacitor (see notes on operation).

Chokes are generally compact but due to their construction method they are heavy. A typical B2 Classified choke for a 58 watt T8 lamp weighs 0.958Kg

Electronic HF

High frequency circuits consist of single devices that combine a current limiting circuit, the starter and power factor correction in a single housing. A typical electronic HF ballast contains approx 90 components.



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

The dimensions of electronic ballasts are completely different to a typical choke. Long and slender with a section of 21x 30 for linear lamps and or a rectangular/square footprint of say 123 x 79 for compact lamps.

Weight is also a major benefit with electronic ballasts. If we compare a typical 58 watt choke, classification B2 (CELMA) at 0.958kg, to the equivalent HF ballast at 0.280kg, you can see at a glance one of the advantages HF has over conventional chokes. Twin circuit HF ballasts are the same weight as single ballasts and offer even greater savings.

Another advantage of Electronic ballasts is multi lamp operation. The ability to control up to 4 lamps from a single device has revolutionised the way we design manufacture and operate our lighting.

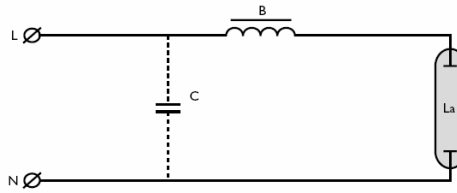
OPERATION

Electromagnetic

Advantages are robust and durable with exceptional operating life providing they are properly maintained.

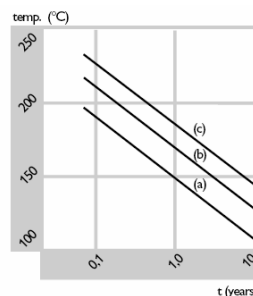
Disadvantages however are many.

1. **Power factor.** Current in lamp/choke circuits exhibits a phase shift with respect to the applied voltage. The current lagging behind the voltage results in a typical power factor of 0.5 inductive. Separate or local power factor correction must be undertaken.



Power factor correction with a parallel compensating capacitor

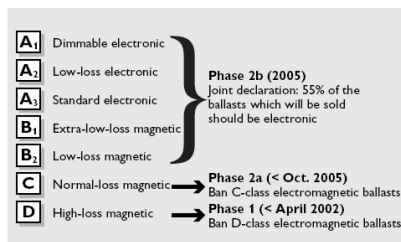
2. **Starting current.** Fluorescent lamps do not ignite at mains voltage. To ignite the lamps, a starter is employed to preheat the lamp electrodes and to give a peak voltage high enough to initiate the discharge. If the starter is of the glow bottle type, these should be replaced at the same time as the lamp is replaced.
3. **Sensitivity to mains voltage fluctuations.** Variations of mains voltage cause fluctuations of current through the lamp with a subsequent change of lumen output.
4. **Temperature.** Chokes have a maximum temperature that must not be exceeded. Maximum coil temperature t_w is marked on the choke. Typical t_w value is 130°C. A 10% temperature rise above the t_w will halve ballast life. (However chokes can withstand much higher ambient temperatures than HF ballasts.)



The nominal life of choke coils in relation to the permitted rated maximum operating temperature of a ballast winding t_w , dependent on insulation material:
 a) class A: t_w 105 °C,
 b) class E: t_w 120 °C,
 c) class F or H: t_w 130 °C.

5. **Power losses.** Ballast losses are normally published as 'cold' values, meaning that the ballast is either not energized, or at most only very shortly, and the ballast winding is at ambient temperature (25 °C). In practice the ballast will more or less reach the marked Δt value and then the copper resistance is approx. 25 per cent higher than in the 'cold' situation. Therefore, the 'warm' losses in practice will be 10 - 30 per cent higher than the manufacturers published values.
6. **Maintenance.** Chokes require separate starters and power factor correction capacitors. Glow starters should be replaced at the same time that the fluorescent lamp is replaced on any particular circuit. This is not necessary for electronic starters. With time, the capacity of the power factor correction capacitors reduces. This will increase the VA of the system load and increase transient spikes in the mains when switched.
7. **CELMA classifications.** The European Community has agreed upon a new directive for controlling the losses incurred by the operation of electromagnetic control gear for fluorescent lamps. This directive is based upon the Energy Efficiency Index (EEI) as agreed by the Committee of European Luminaire Manufacturers Association (CELMA). The Directive required by 2005, that 55% of all ballasts place on the market should be high frequency. These are generally CELMA Class A1, A2 or A3. The rest may consist of

electromagnetic ballasts of CELMA Class B1 or B2. If this percentage is not reached, the European Community will review what further measures can be taken.



- Noise.** The electric current passing through the coil of a choke causes a magnetic field, which arranges the elementary magnetic particles of the ballast iron. The ordering of the elementary magnets causes a certain deformation of the iron (magnetostriction), resulting in the iron expanding in certain directions. The magnetic poles exert forces of attraction in the air gap of the ballast core, resulting in a noise of 100 Hz and higher harmonics.

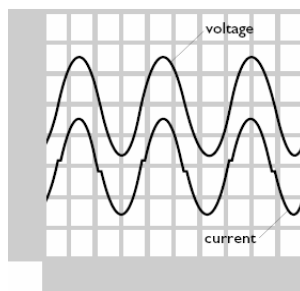
Electronic HF

The advantages of HF ballasts are many as you would expect from a technology developed from the original electromagnetic solutions.

We have already seen that device count within a luminaire is greatly reduced by the introduction of HF ballasts. Multiple lamps can be operated from a single device and wiring is therefore minimised.

New lamp technology such as the T16/T5 lamp has been designed specifically to operate on a HF circuit, no electromagnetic solution is available.

- Power factor.** The phase angle between the fundamental wave of the mains voltage and the fundamental of the mains current is given by ϕ . This angle can be calculated or measured, and in the case of HF ballast circuits is nearly zero degrees (see Fig below), so extra compensation with compensating capacitors, as is the case in the electromagnetic circuits, is not necessary.



The near-zero phase angle in an HF ballast circuit

- Starting.** A fluorescent lamp with cold cathodes needs 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). Improved preheating of lamp cathodes guarantees a warm start and increases lamp life when compared to a switch start circuit.
- Sensitivity to mains.** Electronic HF ballasts use sophisticated control circuits that monitor the mains voltage and can adjust the lamp power to compensate for the European voltage which is 230V +/- 10%. Electromagnetic chokes are voltage specific.

4. **Lifetime.** The overall lifetime of an electronic ballast is determined by the lifetime of each individual component employed in the ballast and the effect on them of voltage, current and temperature. 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 initial burn-in period, early failures in the field are very limited.
5. **Temperature.** All HF ballasts have a Tc point marked on the case of the ballast. This measurement point gives the luminaire designer a point to measure the thermal characteristics of their individual fittings and thereby adjust the thermal dynamics to maintain an optimum operating temperature. One of the reasons for the increase in the failure rate at higher temperatures is the temperature dependency of the capacitors employed, especially the electrolytic buffer capacitor. Long periods of high temperature operation (exceeding max tc) will result in a drying up of the liquid in the electrolytic capacitors and possibly the degradation of solder contacts. Operating life will be reduced and other problems may be experienced such as lamps switching off or failing to strike.
6. **Power losses.** HF ballasts use solid state components to replace the inefficient copper iron of the electromagnetic circuit. Losses through ohmic resistance of the winding and hysteresis in the core are more than halved.
7. **Maintenance.** HF ballasts are maintenance free, no starter or capacitor to replace
8. **CELMA.** Fully compliant with the CELMA classification.
9. **Noise.** No moving parts and as such no opportunity for air gaps within laminations to oscillate and cause audible noise.
10. The high frequency operation of the lamp is above the frequency at which the human eye is capable of detecting it. Therefore living and working under HF fluorescent lighting is more comfortable than magnetic which flickers at 100Hz – well inside the flicker frequency that the eye can perceive.

APPLICATION

This is really where Electronic ballasts make the greatest contribution to an efficient lighting installation.

Multi-lamp operation reduces component count and eases installation. The reduction in components and the use of efficient technology reduces losses and as such increase efficiencies further. The proper preheating of the lamp as defined by the lamp standards provides the best switching characteristics for each lamp. Multi lamp and multi wattage ballasts now exist that avoid duplication of product; one solution fits all.

Safety is of prime importance with emergency lighting and the development of inverter technology, especially combined ballast invertors revolutionising the emergency lighting market.

We haven't gone into great detail as to how HF technology works but as its name suggest the ballast shifts the operating frequency of the ballast from mains 50Hz to the region of 42kHz. As a result of increased efficacy in the lamp at these higher frequencies, less power is required to achieve the same light output. By operating at such a high frequency electronic ballasts are able to eliminate the stroboscopic affect inherent in electromagnetic circuits. Flicker free lighting with no audible noise.

Dimming is something we haven't discussed and HF technology provides the platform for the efficient dimming and operation of fluorescent lamps. Shifting the frequency within the ballast affects the impedance of the circuit and reduces lamp output. Noise free and efficient, the reduction in energy consumed related to light output is almost linear.

Environmental considerations

We live in a world where energy and electricity were once treated as a commodity that was cheap and plentiful. The reality is somewhat more disturbing in that fossil fuels are limited and major changes in

the way we consume power must come into effect sooner rather than later. The increased demand and the effects of global warming have had a tremendous impact on environmental legislation. The WEEE directive looks at recycling of electrical and electronic products at end of life and RoHS has seen the banning of certain hazardous materials in luminaires and associated components. Waste is measured in weight as shipping and transportation have a major impact on the environmental footprint of each product and the lower weight penalty of HF ballasts at end of life will contribute further to saving the planet.

Electronic ballasts are energy efficient in use and in transport both at beginning and end of life. They are a positive benefit to the environment and the following sample calculation of an installation in an office proves these benefits over those of magnetic ballasts.

Quick Economic Assessment Template		
1.	Scheme requirements	Information and Values
	Project name (building area)	
	Size of area L x W x H (m)	
	Maintained illuminance (lux)	
	Overall Uniformity U _o	
	UGR limit	
	Lamp Ra	
	Reflectance of surfaces C, W, W _p	
	Room Index RI = (L + W) ÷ hm(L+W)	
A	Expected scheme (design) life (years)	
B	Annual operating hours (h)	
C	Unit cost of electricity (€/kWh)	

Quick Economic Assessment Template		
2.	Scheme options	Information and data
	Lamp type	
	Lamp life (design life) (h)	
	LSF at end of design life (lamp survival factor)	
	Initial lamp lumens (lm)	
	LLMF at end of design life	
	Lamp lumens at end of design life (lm)	
	Luminaire type	
	UF of luminaire at RI and reflectance	
	LMF at time of clean	
	Ballast type	
	Ballast life (design life) (h)	
	BSF (ballast survival factor) at end of design life	
D	Number of luminaires in scheme	
D1	Total circuit watts per luminaire (W)	
D2	Total number of ballasts in a luminaire	
D3	Total number of lamps per luminaire	
D4	Number of starter switch in luminaire	
D _p	Total installed power for lighting scheme D _p = D x D1 (W)	

Quick Life Time Economic Assessment Template		
3.	Installation and operating costs	Information and Data
F	Luminaire cost complete with lamp (€)	
G	Fixing cost per luminaire (€)	
E	Total installation cost of luminaires $E = (F+G) \times D$ (€)	
H	Annual energy used by scheme $H = (B \times D \times D1) \div 1000$ (kWh/year)	
I	Energy cost per year $I = H \times C$ (€/year)	
J	Total energy cost for design life $J = I \times A$ (€)	
K	Cost of replacement lamp (€)	
L	Cost of labour to replace lamp (€)	
R	Cost of re-lamping in scheme life $R = (K + L) \times D \times D3 \times W$ (€)	
M	Cost of replacement starter switch (€)	
N	Cost of labour to replace starter switch (€)	
	Number of starter switch changes in scheme life	
S	Cost of starter switch replacement in scheme life $S = (M + N) \times D \times D4 \times W$ (€)	
O	Cost of replacement ballast (€)	
P	Cost of labour to replace a ballast (€)	
	Number of ballast changes in scheme life	
T	Cost of ballast replacement in scheme life For HF, $T = D \times D2 \times 0.1 \times (P+O) \times (A/20)$ (€) For EM, $T = 0$ (for this scheme)	
Q	Cost of cleaning a luminaire (€)	
V	Number of times luminaires are cleaned in scheme of life $\text{Int}(Ax(B-0.1)/50,000)$	
U	Cost of cleaning luminaires in scheme life $U = D \times Q \times V$ (€)	
W	Number of group lamp changes in scheme life EM @ 10,000 (h), HF @ 15,000 (h) intervals $= \text{Int}(Ax(B-0.1)/(15,000 \text{ or } 10,000))$	
Mc	Total maintenance cost in design life $Mc = R + S + T + U$ (€)	
Total	Cost of scheme over life of scheme $E + Mc + J$ (€)	

Worked example for testing a spread sheet calculation formula based on the algorithms here

Assumptions

	HF	EM
A	20 years	20 years
B	2,500 hrs	2,500 hrs
C	0.133 €/kWh	0.133 €/kWh
D	320	360
D1	72W	86W
D2	1	2
D3	2	2
F	€157.66	€128.90
G	€42.86	€42.86
K	€4.3	€4.3
L	€1.8	€1.8
M	€0.0	€0.57
N	€0.0	€0.14
O	€28.60	€4.30
P	€11.40	€7.15
Q	€4.30	€4.30
V	9	9
W	3	4
Lamp life to group lamp change	15,000 hrs	10,000 hrs
Note 1	Lamp life is based on normal office use with up to 8 switchings per day	
Note 2	Ballast life for HF is based on 0.25%/1000 hrs i.e. 10% failure at 50,000 hrs and 50% failure at 80,000 hrs For EM, no failures are expected before 100,000 hrs	

Installation cost (€) E = D x (F + G)	
HF	EM
$E = 320 \times (157.66 + 42.86)$ $= 64,166 \text{ €}$	$E = 360 \times (128.90 + 42.86)$ $= 61834 \text{ €}$

Maintenance cost (€) Mc = R + T + U	
HF	EM
$R = [(M+N) + (K+L)] \times D \times D3 \times W$ $= [0 + 6.1] \times 320 \times 2 \times 3$ $= 11,716 \text{ €}$	$R = [(M+N) + (K+L)] \times D \times D3 \times W$ $= [0.71 + 6.1] \times 360 \times 2 \times 3$ $= 14,710 \text{ €}$
$S = (M + N) \times D \times D4 \times W$ $= 0 \text{ €}$	$S = (M + N) \times D \times D4 \times W$ $= 1,757 \text{ €}$
$T = D \times D2 \times 0.10 \times (P + O)$ $= 320 \times 1 \times 0.10 \times 40.00$ $= 1,280 \text{ €}$	$T = D \times D2 \times 0 \times (P + O)$ $= 0 \text{ €}$
$U = D \times Q \times V$ $= 320 \times 4.3 \times 9$ $= 12,386 \text{ €}$	$U = D \times Q \times V$ $= 360 \times 4.3 \times 9$ $= 13,932 \text{ €}$
Therefore:	Therefore:
$Mc = R + S + T + U$ $= 25,382 \text{ €}$	$Mc = R + S + T + U$ $= 30,399 \text{ €}$

Energy cost for design life J = A x I (€)	
HF	EM
$J = A \times B \times C \times D \times D1 \div 1000$ $= 20 \times 2,500 \times 0.133 \times 320 \times 72 \div 1000$ $= \text{€ } 153,216$	$J = A \times B \times C \times D \times D1 \div 1000$ $= 20 \times 2,500 \times 0.133 \times 360 \times 86 \div 1000$ $= \text{€ } 205,884$

SUMMARY		
	HF	EM
Installation cost E $E = D \times (F + G)$ (€)	€ 64,166	€ 61,834
Maintenance cost M_c $M_c = R + S + T + U$ (€)	€ 25,382	€ 30,399
Energy cost for design life (€) $J = A \times I$	€ 153,216	€ 205,884
TOTAL = E + M_c + J (€)	€ 242,764	€ 208,682
	86.0%	100%

Other considerations which will affect the installation costs and maintenance costs	
HF	EM
Reduced cable sizing and associated equipment, and labour due to lower installed load of 23.04 kW	Increased cable sizing due to higher installed load of 30.96 kW.
Power factor of installation will remain at unity (or near unity) for design life.	Power factor capacitors will loose capacitance over time. This will have the following effects: <ul style="list-style-type: none"> 1) VA of installation will increase 2) Increased demand on power grid 3) Cost of electricity will increase for those paying on VA 4) Increased risk of tripping local circuit fuse 5) Cost of supplying and replacement of capacitors during design life
High frequency operation of fluorescent lamp is flicker free, therefore more comfortable to work under.	50 Hz supply frequency creates 100 Hz flicker which can affect certain medical conditions.
At the end of lamp life, the ballast will shut down the circuit and not try to restart the lamp.	At the end of lamp life the glow starter will repeatedly try to start the lamp.

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