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Optimal selection and operation of ballasts for fluorescent lamps

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Content

1 Magnetic ballasts for fluorescent lighting

When talking about economic operation of fluorescent lamps everybody thinks of electronic ballasts, causing lower losses than conventional magnetic ballasts. It is usually forgotten to mention that today's magnetic ballasts are no longer designed to yield lowest purchase price but minimized losses. The price impact of this is insignificant. Under these circumstances the whole topic remains to be reconsidered.

The efficiencies of technical devices and processes are normally rated as percentages. Just with light this does not really match, since with respect to the perception of brightness the human eye is differently sensitive to different colours. Therefore the sensitivity of a standardised average eye has already been integrated into the unit for assessing the brightness of light sources. This unit is called lumen (plainly the Latin word for light). Hence, the efficiencies of lamps and luminaires need to be given in lumens per watt. This and only this indication is appropriate to measure and compare which technical device generates most light per unit of drawn electrical power.

Theoretically an efficiency of 683 lumens per watt (lm/W) can be achieved. This, however, is only valid for mono-chromatic green light with a wavelength of 555 nm, where the human eye has its greatest sensitivity. So the »greenest« assumable lamp is indeed green. Irrespective of any political opinion, however, it remains more than questionable whether we really want to illuminate streets, squares, halls, offices, supermarkets or even living rooms in this way. White light – or what we consider white when mixing all colours from 380 nm to 780 nm wavelengths – yields a theoretical maximum of 199 lm/W. Setting this equal to 100 % brings fluorescent lamps already considerably closer to the desired 100 % ideal than a modern diesel engine is. Speaking in these terms, an incandescent lamp could merely be compared to a vintage steam locomotive.

1 Magnetic balasts have no lobby

The European Commission set out to support such trends towards such efficient lighting techniques and in June 1999 released the first draft of a Directive »with the objective to accelerate the transition of the Community industry towards the production of electronic ballasts and the overall aim to move gradually away from the less efficient magnetic ballasts and towards the more efficient electronic ballasts which may also offer extensive energy-saving features, such as dimming«. This sounds as if it went without saying that an electronic ballast is

- always dimmable and
- always the more energy efficient choice.

Back to the latter item in Section 3. Adding to this, the EU first of all classified fluorescent lamp ballasts by the overall power intake of the ballast and lamp circuit, targeting at gradually phasing out the less efficient models. For instance, the classes and limits for the most common linear lamps are displayed in table 1. The clue about class A1 is that these values refer to dimmable electronic ballasts. A ballast is classified A1 if it fulfils the following requirements:

- at 100 % light output setting the ballast fulfils at least the requirements of class A3;
- at 25 % light output setting the total input power does not exceed 50 % of the power at the 100 % light output setting;
- the ballast must be able to reduce the light output to 10 % or less of the maximum light output.

Now it would have looked somewhat odd to see the losses decreasing from class D all through class A2 but then to come across the inconsistency of an increase again towards the »upper class« A1 [1]. So an appropriate definition was invented that says the rated power is that measured at 25 % light output, since a dimmable system will not always be run at full power.

This is just as logical as saying a car's engine does not always need to supply its maximum power, so if the car's top speed is 200 km/h, let's rate the engine power necessary to drive the car at 100 km/h as the nominal engine power.

Why is this? What does the magnetic ballasts' lobby say and do about this?

Unfortunately such lobby does not exist at all because **all** the European manufacturers of magnetic ballasts, except one less significant company in Bulgaria, also produce electronic ballasts or at least offer them as commodity. Now it is not possible for a company to promote a product with both a lower price and a several times longer lifetime expectancy against an alternative product from their own portfolio, which generates several times more turnover, of profit not even to speak.

Hence, **electronic ballasts** are **promoted** with quite a number of **advantages**:

① The luminaire exhibits a better overall efficiency, which is not so much due to the lower losses in the ballast but in the first place relates to the better lamp efficiency when operated at high frequency (about 20 kHz to 60 kHz). Accordingly, the lamp is fed with a lower input power. In table 1, for instance, the power intake of a 58 W lamp is given as 50 W when operated on an electronic ballast. To be registered as class A2, such a ballast together with the lamp would need to have a power intake not exceeding 55 W. Hence, this is impossible for a magnetic ballast because the lamp alone is rated 58 W here.

② The 100 Hz flicker is avoided at this high lamp operating frequency.

③ Most electronic ballasts provide a warm start capability (cathode pre-heating before ignition), reducing wear of the lamps.

④ Modern electronic ballasts are also available with the so-called cut-off technology, switching off the cathode heating as soon as ignition was successful. This reduces lamp wear and saves even more energy.

⑤ The lamp life is about 30% longer – provided the electronic ballasts avail of the so-called warm start capability.

⑥ Electronic ballasts are also available with immediate start feature.

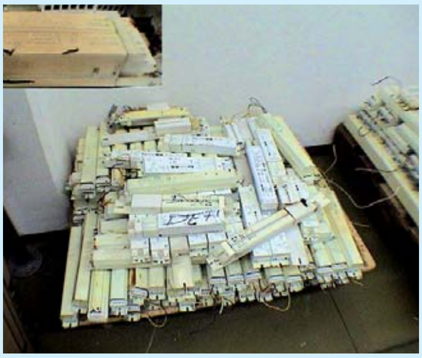
⑦ Defective lamps are switched off automatically rather than harassing people with the constant flashing of the everlasting restart attempts (and on top of this causing excessive losses in the ballast).

⑧ Electronic ballasts facilitate the use of the even more efficient T5 lamps which work only with electronic ballasts.

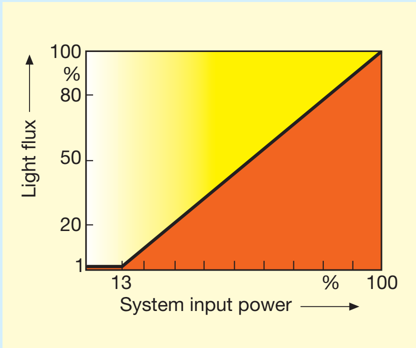
⑨ Electronic ballasts may provide additional energy savings through dimmability and potentially through automatic, adapted lighting control.

Table 1
Values and classes of linear fluorescent T8 lamps with ballasts

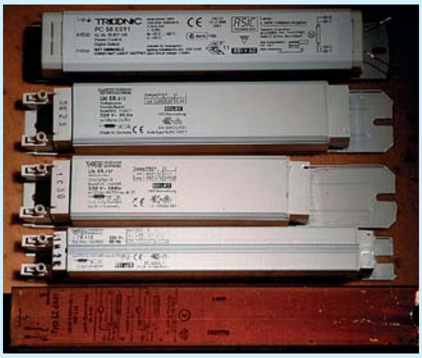
Rated lamp power		Maximum input power of ballast and lamp circuit (values according to old Directive 2000/55/EU)						
		Class						
50 HZ (magnetic)	HF (electronic)	D	C	B2	B1	A3	A2	
15 W	14 W	> 25 W	25 W	23 W	21 W	18 W	16 W	
18 W	16 W	> 28 W	28 W	26 W	24 W	21 W	19 W	
30 W	24 W	> 40 W	40 W	38 W	36 W	33 W	31 W	
36 W	32 W	> 45 W	45 W	43 W	41 W	38 W	36 W	
38 W	32 W	> 47 W	45 W	45 W	43 W	40 W	38 W	
58 W	50 W	> 70 W	70 W	67 W	64 W	59 W	55 W	
70 W	60 W	> 83 W	83 W	80 W	77 W	72 W	68 W	



❶ **Electronic ballast failures of the Eidgenössische Technische Hochschule Zürich in one year**



❷ **Power intake behaviour of an electronic ballast according to manufacturers documentation**



❸ **Samples tested as described here**

2 Advantages of electronic ballasts are relative

However, all of these advantages of electronic ballasts have to be seen in a relative light:

① Unfortunately table ❶ only gives the absolute electrical ratings, saying nothing about the light output of the lamp, which, as the lighting industry unofficially confirms, is 4 % lower when the same lamp is operated on an electronic ballast. Though quite advantageous it is, the EU classification scheme does not reflect this in any manner. Furthermore, the design of **all classes** of magnetic ballasts nowadays deviates substantially from the ratings (see Section 5 of this chapter).

② The 100 Hz technique is promoted as the ultimate flicker free progress for TV sets. Hence it may be doubted whether it is to be seen as a disturbance at all. The flickering would not even provide any topic at all if ZVEI, the trade association of the German electrical industry, had not decided to abandon the proven serial (lead-lag) compensation of fluorescent lamps and return to generic parallel compensation. After all, the arguments forwarded against the lead-lag compensation are not due to the principle, but rather the capacitances that were rated too high decades ago accounting to different technical environments than we have nowadays (see Chapter 4).

③ The warm start capability may come as an extra at an extra price with electronic ballasts; for magnetic ones it has always been an inherent constituent due to the principle since the beginning of fluorescent lighting. There is no other way.

④ The cut-off technology may come as an extra at an extra price with electronic ballasts; for magnetic ones it has always been an inherent constituent due to the principle since the beginning of fluorescent lighting. There is no other way.

⑤ Lamp lifetime tests are carried out using magnetic ballasts with conventional glow starters rather than with the advantageous electronic starters (see Chapter 5) which would let the lamp live at least as long as an electronic ballast would. Even within the lamp and luminaire industry these glow starters are designated as »industrial loose contacts« – an unsupportable technique which replaces each starting process with a number of starting attempts. Hence the lamps usually blink and flash several times before burning properly, while the number of starts is named as a crucial factor for lamp ageing. Apart from this, the advantage of a longer lamp life is impaired and often more than outweighed by a much shorter lifetime expectancy of the electronic ballast (Fig. ❶).

⑥ When electronic ballasts are being promoted as featuring the extra of an »immediate start« capability this means that the warm start capability, which would have come at an extra price, has been omitted. How good that, on account of system constraints, this is not possible at all with magnetic ballasts! The lamps will be grateful for this. As a compromise extremely rapid electronic starters are available on the market, limiting the preheat period to about half a second. Thus the major part of the advantage is bought in at only a minor fraction of the disadvantage [2].

⑦ With magnetic ballasts incessant flashing or permanent pre-heating operation of overaged lamps can also be avoided if electronic starters are used.

⑧ While T5 lamps are specially designed for operation on electronic ballasts, they can just as well be driven with magnetic ones. With some lamp types, however, it is required to use the 400 V phase-to-phase voltage of the mains. Starters for 400 V are already available [2].

⑨ The advantages of electronic ballasts are usually phrased in a way so that one might believe they were by default dimmable, but there can be no talk of this. Rather, dimmability still doubles the high price, and dimmable ballasts require a second line for conducting the control signals. Because the internal wiring of the electronic ballast does not provide a safe insulation between the control and the power circuitry the control line has to be made in a way strong enough to withstand the power line voltage and short-circuit current, usually 250 V, fused 16 A.

3 Advantages and disadvantages of electronic ballasts

Supplementary to this comes the curious fact that electronic ballasts are promoted as having lower internal heat losses, while named Directive **allows higher losses in an electronic ballast than in a magnetic one**. For instance, in table ❶ we learn that a 58 W lamp together with a magnetic ballast must not exceed a consumption of 64 W to comply with the requirements of class B1. This allows for a loss level of 6 W. However, when we shift to class A3, the lamp power drops to 50 W and the systems power to 59 W, allowing for a loss level of 9 W for the allegedly better ballast (Fig. ❷). This does not really matter so much, though, since this Directive fixes the entire gross power consumption of a system as a criterion. Basically this yields a correct approach, yet the good idea turns out as a disadvantage for magnetic ballasts, because, as mentioned earlier, electronic ballasts quite officially feed less than the power rated for 50 Hz operation into the lamp.

But unofficially also magnetic ballasts feed less than this into the lamp. A deliberate usage of the very generous tolerance margin, which in principle would not any longer need to be so generous for today's precise production methods, makes this possible. Still, even with this ballast design, the same lamp is about 4 % brighter than the same lamp with an electronic ballast, as will be shown in Section 5 of this chapter.

Hence, named Directive so far aimed at phasing out merely the classes C and D, which was done in November 2005 and May 2002, respectively, and which indeed is not a pity – and by far not a displacement plan for magnetic ballasts, as had been the initial intention and is still often believed even within the lighting industry. After all there would have been little sense in doing so, since, as the directive itself mentions at a different point, the improvement steps so far defined can be achieved with a cost premium around 2 € per lamp, while all improvements necessitating a conversion to electronic ballasts comes at an additional cost of 20 € per lamp.

4 Efficiency measurements on various ballasts

While this is so, the values in the Directive refer only to operation at rated voltage and assume that the lamp will be fed with its rated power then. Now if the actual power input into the lamp is already considerably less than the rating at rated voltage, then what will happen when the voltage is reduced even further, e. g. to a level where the lamp with magnetic ballast is fed only with the power rated for operation with an electronic ballast (table ❶) or even substantially less than that? To find out, five different ballasts for a 58 W lamp were taken under test (Fig. ❸):

- One stone-old ballast from an installation that had already been knocked down in 1987, still being rated 220 V and of course not efficiency classified and thereby falling into class D according to table ❶.
- One new »superslim« magnetic ballast, inevitably falling into class C, since in electrical engineering restrictions of space nearly always come at the price of restricted efficiencies.
- One new magnetic ballast efficiency class B2.
- One new magnetic ballast efficiency class B1.
- One mint condition electronic ballast rated efficiency class A3.

On each of these five samples all required parameters were measured, always using the same lamp:

Active and reactive power across the whole system, active power (loss) across the ballast, and of course the light output of the lamp. A short excerpt of the results is listed in table ❷, and a graphic evaluation of the complete results is given in Fig. ❹.

Unfortunately, on account of the high output frequency at the terminals of the electronic ballast, it was not possible to measure its output power. This is not a tragedy, though, since the most important data, system input power and light output, could be measured.

5 Assessment of the measured values

The following can be concluded from the results:

- On the electronic ballast neither system input power nor light output vary with varying voltage. So the device under test fully compensates variances of the supply voltage within the tested range, which is usually seen as an advantage – and one commonly expected from electronic ballasts. A deliberate variation of power input and thereby of light output via the feeding voltage, however, is therefore not feasible.
- Of course the energy efficiency comparison turns out best for the electronic ballast at 230 V, but at 200 V the A3 electronic one is only more about the same as the class B1 and even the class B2 magnetic ballasts, and at 190 V the electronic one performs poorer! So at 190 V supply voltage the B1 and even the B2 should be classified as A3, since the efficiency of the A3 model has not altered, while those of both the B1 and the B2 models have exceeded it!
- The information of the light output with electronic ballasts being about 4% reduced against that of efficient magnetic ballasts at rated input **voltage** (not necessarily rated input power – see next bullet point) finds its confirmation.
- The rated lamp power is not always reached precisely at rated voltage. Other than the old ballast, the later magnetic ballast models of all classes reach their rated power only considerably above the rated system voltage. At 230 V, however, the electric lamp input power still falls considerably below the 58 W rating. After all that has been said so far, such design, e. g. deliberate utilisation of the permitted minus tolerance, must be seen as a reasonable approach.
- Still, this does not yet mean that the electric values are now totally comparable to those of an electronic ballast! With classes C, B2 and B1, the light output is around 5000 lm, while the electronic ballast tested here provided only 4720 lm.
- So the improved magnetic ballast models under test only feed about **53.5 W** into the lamp instead of the rated 58 W, and still, the lamp shines **4 % brighter** than with the electronic ballast! Hence, for reasons of objectivity, in order not to compare apples with pares, the electronic ballasts' light output at 230 V would rather need to be compared to those values metered on the improved magnetic models at **222 V** actual voltage.
- At **this** point of operation the actual lamp inputs were only more around 50 W – matching the rating given for an electronic ballast. This makes the deviating lamp ratings for operation with magnetic versus electronic ballast operation appear relative and raises doubts about the quantity of efficiency improvement at high frequencies. The confinement to this statement is the lack of measured electric output power at the electronic ballast. However, the systems' power intakes with electronic A3 and mag-

Table ❷ Excerpt from the measurement results

Type (device under test)	Metering conditions	Measurements DIAL U in V	P_{tot} in W	P_{Bal} in W	P_{Lamp} in W	Φ in lm
T8 lamp 58 W with magnetic ballast EEI = B1		220	56.24	6.54	49.70	4662
		222	57.24	6.84	50.41	4718
	$U = U_N$	230	61.42	8.01	53.36	4952
		240	66.40	9.60	56,72	5198
	$P = P_N$	244	68.53	10.31	58.00	5306
		250	71.60	11.50	59.91	5420
T8 lamp 58 W with electronic ballast EEI = A3		220	54.85			4723
	$U = U_N$	230	54.80			4718
		240	54.86			4724
		250	54.72			4723

❹ Plotted results of measurement

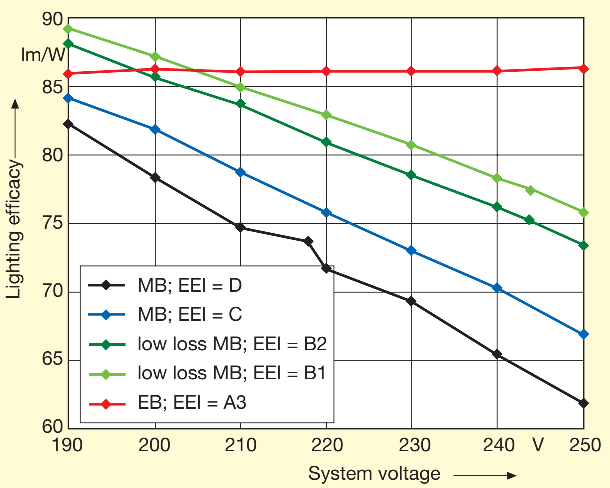


Table 3 Power savings and light losses at operating voltage reduced from 230 V to 190 V

Type (device under test)	ballast losses drop by	electical lamp power drops by	system power intake drops by	overall efficiency improves by
magnetic ballast, class D	65.9 %	31.2 %	27.1 %	18.6 %
magnetic ballast, class C	70.2 %	38.8 %	36.5 %	15.2 %
magnetic ballast, class B2	70.0 %	37.0 %	35.1 %	12.2 %
magnetic ballast, class B1	69.5 %	38.3 %	36.2 %	10.6 %
electronic ballast, class A3	≈ 0 %	≈ 0 %	≈ 0 %	≈ 0 %

netic B1 **ballasts at the points of equal light outputs** deviated from each other only more by exactly **2.1 W** in order to provide 4720 lm light output in either case (table 2).

- By switching from a poor class C magnetic ballast to a class B1 model the efficiency at rated lamp power is improved by 10 % from 70.3 lm/W to 77.4 lm/W, since the share of ballast losses among the total input power drops from 22.9 % to 15.0 %. The price premium for the more efficient magnetic ballast therefore pays off in nearly all applications, short payback periods guaranteed.
- Contrary to this, the persistent use of very old poor efficiency ballasts – especially if still designed for 220 V line voltage rating – leads to a significant lamp overload with highly over-proportional increase of losses and reduced lamp life but only little increase of light output.
- By reducing the operating voltage from 230 V to 190 V, the efficiency e. g. of a lamp with a class C ballast is improved from 73.0 lm/W to 84.1 lm/W, that is by well over 15 %. When a class B1 ballast is used, the light efficiency still rises from 80.6 lm/W to 89.1 lm/W and hence still by about 10.6 %. So the reduction of the feeding voltage also pays off, especially in cases where poor magnetic ballasts are not replaced with better ones. However, this shall not be an excuse for further operating »old scrap« any longer, for also with high-efficiency magnetic ballasts the fairly simple and usually rather inexpensive voltage reduction technique provides pretty short payback periods. The upgrade from anything to a B1 ballast really is the bargain, and some greater or smaller voltage reduction may come on top of it as a perfection.

6 Efficiency improvement by voltage reduction

The high variance of efficiency even with moderate voltage reduction on a lamp circuit with whatever type of magnetic ballasts has three main reasons:

- Copper loss and approximately also iron loss in the ballast rise by the square of the current. Therefore the power lost in the ballast drops over-proportionally when current is reduced (see table 2 and Fig. 4).
- Lamp voltage increases when lamp current decreases. Therefore electrical lamp power decreases under-proportionally with decreasing supply voltage, while lamp efficiency moderately increases and simultaneously ballast losses dramatically drop.
- On account of this, current drops over-proportionally to the voltage reduction and accelerates the former effects.

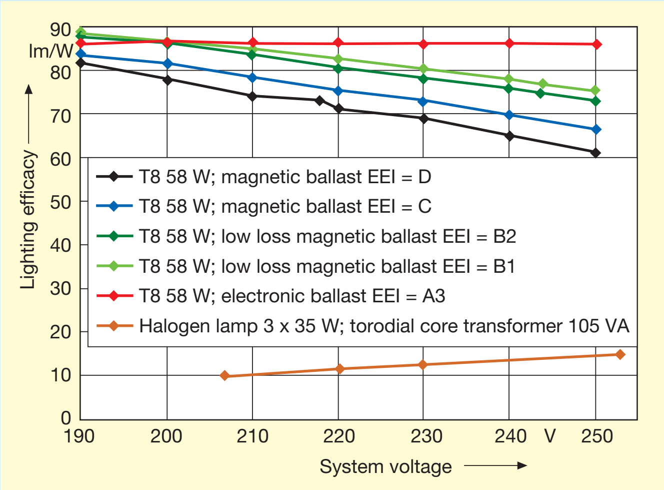
In May 2000, being informed about this, the EU made an amendment to their document that any other measure judged appropriate to improve the inherent energy efficiency of ballasts and to encourage the use of energy-saving lighting control systems should be considered.

Further, the undervoltage extends the lamp life by about 33 % ... 50 %, the voltage reduction plant producers claim. However, ZVEI [3] the trade association of German lamp and ballast manufacturers, points out that also the opposite can happen because the optimum filament temperature is not reached [4]. So far it can only be concluded from the conflicting statements that this issue has not yet been experimentally investigated. Life time tests of longlife devices take a long time by definition. Moreover, ZVEI point out that undervoltage operation, as far as it falls below the permitted tolerance limit of 207 V, represents an operation outside the producer's specification and therefore voids warranty. This is correct but rather relates to the fact that the affected ratings – also those for the compensation capacitors, as explained in Chapter 4 of this booklet – have not been revised any more for decades. However, if the saving technique saves just 5 W all together through improved lamp efficiency and reduced ballast losses, then the lamp saves its own price within 10000 hours of operation. If the lamps at average live as long as this, you may very well lose your warranty, and you still do make a bargain. Your warranty does under no circumstances include more than the purchase cost of a failed lamp, if any, or a ballast, respectively, but to assume a magnetic ballast might fail on account of undervoltage is as absurd as believing your car might fail because you do not always drive full speed. A few other solutions may in certain situations achieve the same effect with an even lower or no price premium at all:

- In some luminaires, 2 smaller fluorescent lamps may be connected in series on 1 magnetic ballast (and 2 starters), as described in Chapters 3 and 4 in this booklet.
- Magnetic ballasts are also available with a 240 V rating. Using these on a 230 V supply will normally not cause any problems, least of all if electronic starters are used. The current is slightly reduced, accompanied by the over-proportional saving effects as described for lower input voltage, but with an even better stability of light because the full voltage is applied. As described earlier in this section, the operation of the modern magnetic ballasts at rated voltage did not match the point of operation with the electronic ballast in the test. Rather, although the electric lamp input power already fell 4 % below the rating with the tested magnetic ballasts, the light output was still 4 % above that of the electronic one. So the operation of these magnetic ballasts at 4 % undervoltage provides a much closer equivalence to the electronic ballast than at rated voltage.

5 Demonstration model for a direct comparison

For a concise insight into the economic potentials, here comes a summary of all the saving quotes. By reducing the voltage from 230 V to 190 V (by 17.4 %) the following reductions are achieved as shown in table 3. It has to be borne in mind, though, that at 230 V and with the class B1 magnetic ballast the lamp already supplied 4.7 % more light than was the case with the electronic ballast (at any voltage between 190 V and 230 V). Therefore the true light loss is not 36.2 % but only 31.5 %. So, to be precise, 46 % more lamps would need to be installed to obtain the same light flux. Their costs need to be balanced against the savings with energy and lamp replacement. Final customers or their contractors will need to calculate this in each individual case. In general you may select to install some 20 % to 30 % more lamps as a compromise, alone because with the more



❻ Measured range expanded – at the bottom the result from a luminaire with three halogen incandescent lamps pops up

even distribution of light a lower total light level may suffice. To calculate this in each individual case is the lighting planners' task.
It is remarkable in this context that the human sensitivity for brightness, as is the case for noise level, is logarithmic. Differently from noise, however, the applied assessment dimensions are linear, so a measured enhancement of luminous density by a factor 10 is perceived as a doubling of brightness, 100 times more light is felt to be triple, 1000 times more seems just 4 times brighter and so on. In the end of a day a number of test persons were not able to say whether certain lamps were operated at 190 V or at full line voltage. One company [14] constructed a demonstration panel for this purpose (Fig. ❺), in which 2 luminaires, each with 2 fluorescent lighting tubes rated 58 W (in lead-lag circuit) are operated, one luminaire at full line voltage and one at 190 V or even just 185 V. So visitors can convince themselves: You actually see no difference in brightness even here where both variants are inevitably viewed simultaneously side by side! A power saving of 23.5 % costs only 4.8 % loss of light. What remains to be subtracted from this saving is the power loss inside the voltage reducer but which is only 13 W in the case of this small unit, i. e. 1 W per each of the maximum 13 lamps that could be connected.
What you do very well see is a difference between the lead and the lag circuit in the lead-lag configuration of each luminaire. The lighting tubes seem to have a slightly different colour shade. **If** anything looks like need for action, then it is this, namely an adequate adaptation of the capacitance ratings for the lead-lag compensation (see Chapter 4 of this booklet).

7 The old Directive 2000/55/EU

After all, when the EU Directive was finally published in September 2000 it read:
»This Directive aims at reducing energy consumption … by moving gradually from the less efficient ballasts, and to the more efficient ballasts which may also offer extensive energy saving functions.«
No more talk of reducing, let alone phasing out the market share of magnetic ballasts – and this is what it should be like, otherwise the prohibition of incandescent lamps would have had to be considered much sooner in order to come from 10 lm/W to 80 lm/W. After this we may continue discussing whether a further increase to 86 lm/W pays off, whether it should perhaps be even 90 lm/W and how much this may cost.
It is common practice within the lighting industry to compare the best electronic ballast to the poorest magnetic model when they come to talk about the efficiency of lighting. Now doing this the other way round and comparing the class A3 electronic to the B1 magnetic model, and doing so at the operation points of equal light outputs, revealed that the difference in electric input is **2.1 W** for a lamp rated 58 W. Hence, it takes about 3000 hours of operation to save 1 €. After all, more attention should be paid to the lamp itself, since there is quite a wealth of more efficient and of less efficient types available on the market.
Well, and all of this is to be seen on the background that fluorescent lamps are a very efficient light source under all circum-stances, regardless of whatever way they are being operated (Fig. ❻). ■

2 New EU Directive for not quite new ballasts

The magnetic ballast is dead? Long live the magnetic ballast! – Also at the regional electrical trade fair Belektro 2008 in Berlin nearly all experts agreed that by way of an EU Directive magnetic ballasts for fluorescent lamps were to be banned from the European markets in the long run. What an error! In fact the opposite is the case. The following paragraphs shall provide clearance how such a misunderstanding could occur and what is really planned to be done.

By and large it became time to decide about further steps. Therefore the EU repealed the Directive 2000/55/EU and replaced it with the Commission Regulation for implementing the »Ecodesign« Directive 2005/32/EC (ErP Directive – Energy related Products) in the area of lighting components in April 2010. **However, other than frequently heard even from lighting experts, this Directive does <u>not</u> incur any plans to abolish magnetic ballasts!**

1 Misunderstanding No. 1

This misunderstanding already arose during the compilation stage of the old Directive because its initial draft 1999/0127 said: »The present proposal would accelerate the transition of the Community industry towards the production of electronic ballasts« and »The overall aim of this Directive is to move gradually away from the less efficient magnetic ballasts, and towards the more efficient electronic ballasts…«, just as if magnetic ballasts always had high losses and electronic ballasts were always the best solution.
Everybody to whom it was of any concern read this very carefully and kept in mind that magnetic ballasts were going to be phased out. Albeit, in the final version which actually went into force the commensurate passage reads: »This Directive aims at reducing energy consumption [in lamps, luminaires and lighting installations etc.] by moving gradually away from the less efficient ballasts, and towards the more efficient ballasts which may also offer extensive energy-saving features.« No more mention of any technology that is to be given preference in achieving this improvement. Now everyone of us knows this situation: When the paper came in it was soon identified as »already known« and filed.
Nobody read the 24-page document again in order to find a minor editorial modification on page 18. Instead everybody preferred to re-

turn to more urgent daily businesses, since it was already known that magnetic ballasts would have to go. What remains as a matter of fact is the prohibition of ballasts classes C and D. They may still be produced within the EU, but are meant for export purposes only. Serious manufacturers note this on their packages (Fig. ❶). Despite this prohibition the old classification pattern, measuring only the overall input power and ignoring both the light output you get for your power input as well as the split of this power input across the lamp and the ballast, was a bit too simplified, since:

- Losses occurring in the ballasts generally represent only a minor fraction of the overall power intake in a luminaire.
- But assessment is carried out based on the lamp power rating, not at all on the actual power fed into the lamp.
- It is not considered in any way how much light you get for your watts. Only what goes into a lighting installation is measured, not what comes out in return.

This provides manufacturers with the opportunity to design a ballast in a way so that it feeds a little less than the rated power into the lamp. At the input terminals of the luminaire this relatively small difference appears as a relatively great difference in ballast losses, since the lamp power is assumed to match its rated value. Probably nobody will notice that a little bit less light comes out. At least this is how you could speculate and utilize the tolerance frames for this, which are quite generous for historical reasons. Obviously the EU did realize that this was a suboptimal solution and hence issued their new regulation.

❶ Magnetic ballasts class C and D are still being produced within the EU, but not for use within the EU

Table ❶ Energy efficiency index requirements for non-dimmable ballasts for fluorescent lamps (excerpt of Table 17 in EU Directve 245/2009)

Lampdata				Ballast efficiency (P_{Lamp}/P_{Input}) – non-dimmable						
Lamp-type	Nominal wattage	Rated/typical wattage		EEI class (for stages 1 and 2)					*EBb*$_{FL}$	
		50 Hz	HF	B2	B1	A3	A2	A2 BAT	50 HZ	HF
T8	15 W	15.0 W	13.5 W	62.0 %	67.9 %	75.0 %	84.4 %	87.8 %	82.8 %	81.9 %
T8	18 W	18.0 W	16.0 W	65.8 %	71.3 %	76.2 %	84.2 %	87.7 W	84.1 %	83.2 %
T8	30 W	30.0 W	24.0 W	75.0 %	79.2 %	72.7 %	77.4 %	82.1 %	87.0 %	85.8 %
T8	36 W	36.0 W	32.0 W	79.5 %	83.4 %	84.2 %	88.9 %	91.4 %	87.8 %	87.3 %
T8	38 W	38.5 W	32.0 W	80.4 %	84.1 %	80.0 %	84.2 %	87.7 %	88.1 %	87.3 %
T8	58 W	58.0 W	50.0 W	82.2 %	86.1 %	84.7 %	90.9 %	93.0 %	89.6 %	89.1 %
T8	70 W	69.5 W	60.0 W	83.1 %	86.3 %	83.3 %	88.2 %	90.9 %	90.1 %	89.7 %
T5-E	14 W	–	13.7 W	–	–	72.1 %	80.6 %	84.7 %	–	82.1 %
T5-E	21 W	–	20.7 W	–	–	79.6 %	86.3 %	89.3 %	–	85.0 %
T5-E	24 W	–	22.5 W	–	–	80.4 %	86.5 %	89.6 %	–	85.5 %
T5-E	28 W	–	27.8 W	–	–	81.8 %	86.9 %	89.8 %	–	86.6 %
T5-E	35 W	–	34.7 W	–	–	82.6 %	89.0 %	91.5 %	–	87.6 %
T5-E	39 W	–	38.0 W	–	–	82.6 %	88.4 %	91.0 %	–	88.0 %
T5-E	49 W	–	49.3 W	–	–	84.6 %	89.2 %	91.6 %	–	89.0 %
T5-E	54 W	–	53.8 W	–	–	85.4 %	89.7 %	92.0 %	–	89.3 %
T5-E	80 W	–	80.0 W	–	–	87.0 %	90.9 %	93.0 %	–	90.5 %
T5-E	95 W	–	95.0 W	–	–	84.1 %	90.5 %	92.7 %	–	90.9 %
T5-E	120 W	–	120.0 W	–	–	84.5 %	90.2 %	92.5 %	–	91.0 %
T5-C	22 W	–	22.3 W	–	–	78.8 %	84.8 %	88.1 %	–	85.4 %
T5-C	40 W	–	39.9 W	–	–	83.3 %	88.9 %	91.4 %	–	88.2 %
T5-C	55 W	–	55.0 W	–	–	84.6 %	90.2 %	92.4 %	–	89.4 %
T5-C	60 W	–	60.0 W	–	–	85.7 %	90.9 %	93.0 %	–	89.7 %
TC-DE	120 W	–	122.0 W	–	–	84.7 %	90.4 %	92.6 %	–	91.0 %
TC-DD	55 W	–	55.0 W	–	–	84.6 %	90.2 %	92.4 %	–	89.4 %

2 The new EU regulation – a lot is really new

This new Directive takes effect in three stages: One year after entry into force preliminary limit values become valid. Three years after entry into force they become one level stricter, and eight years after entry into force these levels will be replaced with yet stricter final limits. This way industry shall be given sufficient time for a conversion. At least this is the principle behind it. The practical implementation is somewhat more lenient. The most substantial novelties are:

1. As an »Ecodesign« directive it does not only provide electrical values but also e. g. maximum limits for the mercury content and minimum values for the lifetime expectancy of lamps.
2. Minimum values for complete luminaires are included – although the only »Requirement« is that »all luminaires … shall be compatible with ballasts complying with the first/second/third stage requirements«.
3. Minimum efficiencies (light output efficacies) are introduced for all common fluorescent and gas discharge lamp types – i. e. for the lamps alone without consideration of the ballast.
4. Apart from this, there are separate limit values for the energy efficiencies of ballasts, measured as the ratio of the lamp power rating divided by the sum of the lamp power rating plus the ballast power loss.
5. In return for this, the division of system power into classes is superseded. Together with items 3 and 4 this is a significant improvement, for the most efficient system can now easily be built up by selecting the most efficient components. Prior to all, the **system power** is no longer addressed as the **efficiency of the ballast alone**, which has lead to many a misunderstanding so far.
6. A most substantial difference at this point is that table 17 (in part reproduced here as table ❶) of this new implementing regulation distinguishes between three different power values of lamps: a nominal power, which is, so to say, only the name of the respective lamp, a rated power for mains frequency operation and a rated power for HF operation. The »nominal« power is usually identical with the 50 Hz rated power unless the latter is not an integer figure but has a decimal. In this case the decimal is omitted. For instance, an FD-38-E-G13-26/1050

T8 (26 mm ∅)		T5 (16 mm ∅)			
		HE (High Efficiency)		HO (High Output)	
Nominal wattage	**Luminous efficiency**	**Nominal wattage**	**Luminous efficiency**	**Nominal wattage**	**Luminous efficiency**
15 W	63 lm/W	14 W	86 lm/W	24 W	73 lm/W
18 W	75 lm/W	21 W	90 lm/W	39 W	79 lm/W
25 W	76 lm/W	28 W	93 lm/W	49 W	88 lm/W
30 W	80 lm/W	35 W	94 lm/W	54 W	82 lm/W
36 W	93 lm/W			80 W	77 lm/W
38 W	87 lm/W				
58 W	90 lm/W				
70 W	89 lm/W				

Table 2 Minimum rated luminous lamp efficiencies, 100 h initial values for T8 and T5 lamps
(Table 1 of Directive 2005/32/EC)

lamp according to ILCOS (International Lamp Codification System) with a power rating of 38.5 W for 50 Hz and 32.0 W for HF has a nominal power of 38 W and is hence called a »38 W (T8) lamp«. In the old Directive the difference between the nominal 38 W and the 32 W HF rating appeared like a 6 W advantage for the HF (electronic) ballast, which it has never ever been. The new approach is to measure, calculate and assess the energy efficiency of a »magnetic ballast for a 38 W T8 lamp« based on an output of 38.5 W and the energy efficiency of an »electronic ballast for a 38 W T8 lamp« based on an output of 32 W, rather than comparing the inputs only.

7. For dimmable electronic ballasts and other remote controllable lamp operating devices there are maximum stand-by losses.
8. Moreover, the power intake – of the lamp as well as the power loss in the ballast – is now to be measured at the point where the light output equals the light output rating of the respective lamp at 25°C ambient temperature. This is a substantial improvement against the present approach to classify only the power intake of the entire system and ignore any possible differences in light output between the uses of different ballasts on the same lamp. Thereby an impartial treatment of both magnetic and electronic ballasts is now granted. The application of two different measures but without respect to the light output comes to an end.

3 Misunderstanding No. 2

At this point unfortunately the second widespread misunderstanding arose. The pitfall is that the old designations A1, A2, A3, B1 and B2 remain in use. A1 continues to stand for dimmable ballasts. Two new classes A1 BAT and A2 BAT (»best available technology«) have been introduced, whereas, again, the former is reserved for dimmable ballasts. However, none of these class designations relates to the old Directive 2000/55/EU, but they are redefined within the new Directive 2005/32/EC. As described above, this is done by means of the ballast energy efficiencies as a percentage value of **the real electrical output power** divided by **real electrical input power**. Now no class is linked to any certain ballast technology any longer, as has been the case so long, such as A for electronic, B (and formerly also C and D) for magnetic except that A1 and A1 BAT are by definition dimmable ballasts. But their efficiencies are defined in terms of the other classes, as used to be the case before.

The lamp efficiencies, however, are not divided into classes. This would have gone way too far, since there are so many different types around. These limits must be taken directly out of one of the countless tables, starting with table 1 splitting double-capped lamps into T8, T5HE and T5HO types. This table (reproduced here as table 2) reveals rather clearly how far T5HO lamps fall behind not only T5HE but also behind T8 lamps. So T5 lamps are in no way generally more efficient than T8 lamps, as is frequently assumed and alleged (also see Section 6). This becomes evident at the very first look at the new documentation. The changes in detail are, as far as energy efficiencies are concerned:

4 The new lamp efficiencies

- **First stage requirements:** One year after the entry into force of the new regulation T5 and T8 lamps shall have at least the rated luminous efficacies as specified in table 1 of said regulation (see table 2), all measured at 25 °C ambient temperature. This appears to be a bit unfair against T5 lamps, though, because for some good reasons they are optimized for an ambient temperature of 35 °C.
- **Second stage requirements:** Three years after the entry into force the requirements for T8 lamps from the first stage will be expanded to all double capped fluorescent lamps, unless their diameter be equal to 16 mm. This is an awkward way of leaving a loop hole for the inefficient T5HO lamps, but it is so far the only obliqueness in this new standard.
- **Third stage requirements:** Eight years after the entry into force fluorescent lamps are not faced directly with any additional efficiency requirements. It only says they »shall be designed to operate with ballasts of energy efficiency class at least A2 according to Annex III.2.2«, but this can be said of any common fluorescent lamp already now. **Note:** It does not say, »The ballast/system shall meet the energy efficiency requirements of class A2 according to 2000/55/EU«, which would have been something entirely different!

5 The new ballast efficiencies

First stage requirements: One year after the entry into force of the new regulation the minimum energy efficiency index class shall be B2 (according to table 17 of 2005/32/EC!) for ballasts covered by table 17, and A1 for dimmable ballasts covered by table 19 (of 2005/32/EC, not of 2000/55/EU, which it supersedes! See table 1 of this chapter).
Parallel with the old Directive, this implies that the ballast's efficiency shall match the requirements of class A3 when set to full power and shall use no more than 50 % of its full power when set to 25 % light output, as used to be the case in the old Directive.
Second stage requirements: Three years after the entry into force there is no change to non-dimmable ballasts for fluorescent lamps. Limits for high-pressure discharge lamps are upgraded, and the stand-by consumption of dimmable ballasts goes from 1 W down to 0.5 W maximum.
Third stage requirements: Eight years after the entry into force the minimum efficiencies of ballasts are:

- η = 71 % for ballasts up to 5 W (nominal power),
- η = 91 % for ballasts from 100 W upwards and
- $$\eta = \frac{P_{Lamp}}{2^{*}\sqrt{\frac{P_{Lamp}}{36}} + \frac{38}{36}P_{Lamp} + 1}$$

  for ballasts between 5 W and 100 W.

This calculation of η is called EBb_{FL} in 2005/32/EC. As described above, this approach yields different efficiency values for the same lamp, depending on whether it is being operated with a magnetic or an electronic ballast if different power ratings are given for either of these. The required efficiencies turn out to be a little bit lower for the electronic ballasts, which is obvious when one enters slightly lower values of P_{Lamp} into the formula.

6 The old and new classes

So also this new document makes no statement whatsoever about any prohibition of magnetic ballasts. Otherwise what sense would there be in defining new values for classes B1 and B2? Rather, there used to be quite an imbalance to the advantage of electronic ballasts in the old scheme according to Directive 2000/55/EU. While it is always argued among experts that one of the advantages of electronic ballasts was the lower internal power loss, even the old Directive 2000/55/EU stated the very opposite! For instance, it said there referring to a 58 W T8 lamp:

- Lamp power with **magnetic ballast**: 58 W,
- systems power with **magnetic ballast** (class B1 – old): ≤ 64 W.
- This allows for a power loss of ≤ 6 W inside the magnetic ballast.
- Converted to the new calculation method, this yields a minimum efficiency requirement of $\eta \geq 58\ \mathrm{W}/64\ \mathrm{W} \approx 91\ \%$, matching the new class A2, rather than B2, which would already satisfy stage 1 of the new regulation! The EBb_{FL} requirement of stage 3 is only $\eta = EBb_{FL} \geq 89.6\ \%$, so it is also easily fulfilled by the good old magnetic ballast!

But at the same time it also said in the old 2000/55/EU document:

- Lamp power with **electronic ballast**: 50 W,
- systems power with **electronic ballast** (class A3 – old): ≤ 59 W.
- This allows for a power loss of ≤ 9 W inside the electronic ballast!
- Converted to the new calculation method, this yields a minimum efficiency requirement of $\eta \geq 50\ \mathrm{W}/59\ \mathrm{W} \approx 85\ \%$ – passing B2 (new) but failing B1 (new), therefore just about compliant with stage 1. The EBb_{FL} requirement of stage 3 is $\eta = EBb_{FL} \geq 89.1\ \%$ here, hence also failed! In other words: The old Directive used to allocate a higher class to a poorer ballast and vice versa!

The **new** classification requires the energy efficiency of a 58 W ballast for a T8 lamp to be 84.7 % in class A3 or 86.1 % in class B1, respectively. It is a bit confusing why the new class B1 requires a higher efficiency than class A3. In fact it also allocates a higher class to a poorer ballast here. This is the case not with all, but with a number of ballasts and may be a remnant of the old definitions for classes B1 and A3, whenever it is better concealed there (see above).

After all this is nothing to worry too much about because these requirements are only a transition to the continuously calculated method of the final stage 3. However, it does become evident that a **magnetic** ballast of class B1 according to the **former (old)** classification has far lower losses than required by the **former (old)** class A3; moreover, it even **complies with the new A2 requirements**! An electronic ballast according to the old class A3, however, just about manages to comply with the new class A3. This conflicting statement so long may have been better concealed and now lurks up.

7 Morals

The question is legitimate whether T5 lamps do not turn out a bit too poor if they are required to be measured at 25 °C ambient temperature, while they were optimized for 35 °C for some good reasons. Also the better lamp efficiency at high frequency is no longer reflected in the new assessment scheme. The EU may have their doubts about the extent of such improvements, and measurements foster these doubts. Although separate lamp power input ratings have been fixed for magnetic and electronic ballasts, there is only one efficiency limit in place. Obviously nobody protested against this. However, it is highly welcome that efficiency limits do exist at all now and that ballasts are assessed separately from the lamps. The ambiguous comparison where the light flux could be slightly minor with an electronic ballast has come to an end. Now both lamp and ballast efficiencies have to be measured at the point of rated lamp light output! It was shown that **a magnetic ballast matching the old class B1 has substantially lower losses than would be needed to comply with the new class A3** – and that the ballast even complies with the new class A2! Albeit, the electronic ballast according to the former class A3 only barely complies with the new class A3. This does not really look like a prohibition of magnetic ballasts but rather the opposite! ■

3 Tandem configuration of fluorescent lamps

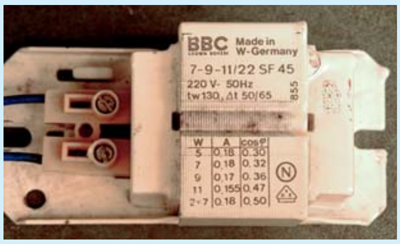
A particular fluorescent lighting tube requires a particular ballast, but often several lamps can be operated on one and the same ballast, and one ballast may be usable for different types of lamps, or one and the same ballast may operate one particular lamp alone or optionally two of them in series. This results in certain differences of operational behaviour. So when designing the electrical circuitry inside a luminaire, a configuration should be selected that yields optimal operational properties.

Advertisements in favour of electronic ballasts occasionally claim that in magnetic ballasts »up to 30 %« of the luminaire's total power intake is absorbed as losses. First of all, it remains to be noted that a statement like »up to«, very popular though it may be, is also totally inappropriate to make any statement at all, unless simultaneously complemented by indicating the mean and the maximum values. The same here: The greatest relative losses occur with the smallest lamps. This can be traced back to a law of nature once called »Paradox of the Big Machine« [5]. In a 58 W lamp, for instance, it is only 13 % (see Section 5 of Chapter 1). Moreover, the piece numbers of smaller lamps are also smaller, and so their overall contribution to the total losses is all the smaller. So the indication »up to 30 %« tells nothing at all.

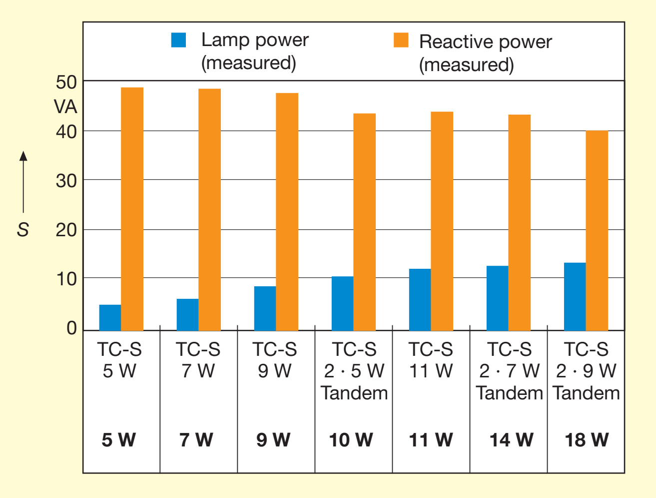
While, on the other hand, this is even understated. For instance, when measuring the power shares on a TC-S lamp rated 5 W and operated with a conventional magnetic ballast, a lamp power magnitude of 5.6 W may be found, along with once again the same magnitude of ballast losses, so in this case you may very well speak of 50 % losses.

1 Different lamps on the same ballast

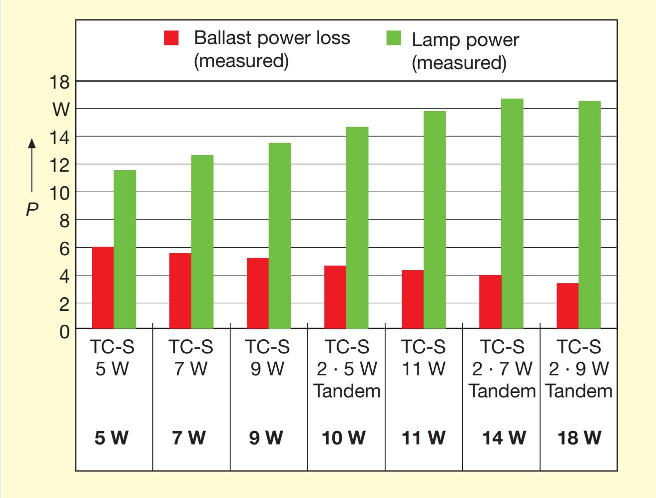
Generally, however, the lamp voltage across smaller, i. e. shorter fluorescent lamps of the same type family is lower than with the longer types of the same series. Thereby, for longer lamps a larger share of the voltage drops across the lamp and a smaller share across the ballast. At the same time the current rating is a bit lower with the longer lamps, while the ballast remains the same (Fig. ❶, Fig. ❷). However, the ballast losses are approximately proportional to the square of the current. So if you replace the 5 W lamp in one and the same luminaire with a 7 W lamp, which is not a problem at all if only the greater lamp length can be accommodated, under the bottom line you receive more lamp power at lower power loss.



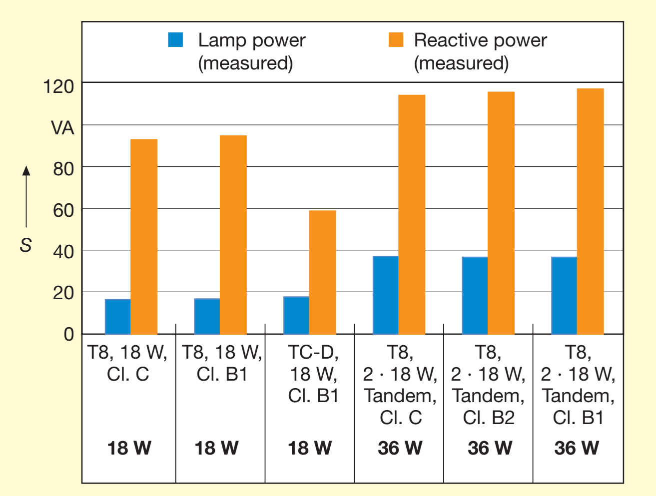
❶ Example of a ballast suitable for operating 4 different single lamps and 3 different tandem configurations
the power factor cosφ increases substantially with higher total lamp power ratings connected



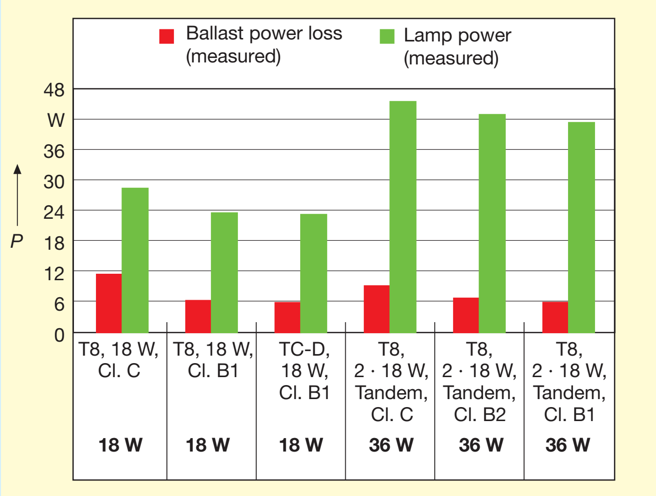
❸ Reactive power of small fluorescent lamps (TC-S), always measured with the same ballas



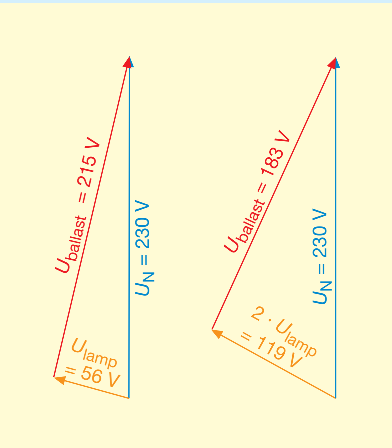
❹ Split of total system active power intake for different TC-S lamp configurations with the same ballast



❺ Reactive power of different fluorescent lamps of equal power ratings on different ballasts



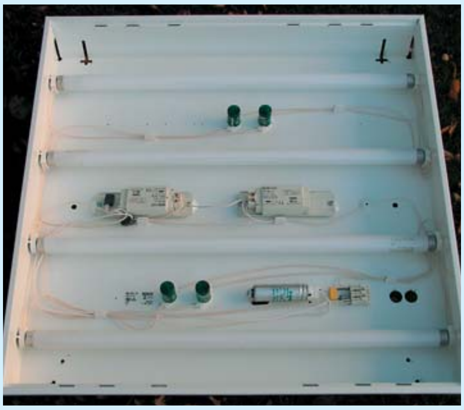
❻ Active power of different fluorescent lamps of equal power ratings on different ballasts



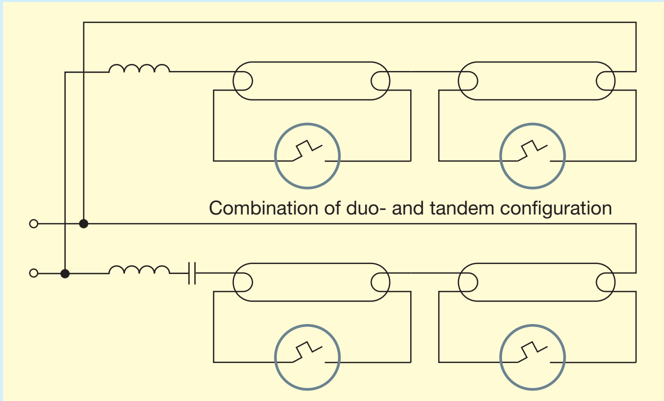
❷ Vector diagram of the voltages;
a) on one TC-S lamp 9 W,
b) on a serial connection of two TC-S lamps 9 W

But this is still not the full story, since the lamp voltage across the TC-S lamps rated 5 W, 7 W and 9 W is so low that the common mains voltage of 230 V allows two of these lamps to be operated in series on one ballast. In effect, this doubles the lamp voltage again, of course. Since the same ballast is used for this so-called tandem connection as for the single operation, the actual current and thereby the resulting lamp power when operated in tandem lie slightly below the ratings. In order to minimize the deviation, the magnetic ballasts are designed in a way so that in single mode the current and power magnitudes are slightly above the ratings. In total, the effect is that the ballast is always less loaded, the more lamp power rating is connected to it. More lamp load leads to an absolute drop in losses and thus, in relative terms, saves triple, reducing both reactive power and hence the demand for compensation (Fig. ❸) and ballast losses (Fig. ❹) as well as improving the lamp efficiency by not using its full capacity (see Section 7 of Chapter 1).

While lamp efficiencies improve when the lamps are not operated at full power, efficiencies also drop when the lamps are operated at overload. This was revealed during a measurement carried out by a well respected and independent lighting institute [6], recording not only the electrical values but along with these the light output (Table 3.1). In this test the 9 W lamp turned out at the end of the scale, since the 5 W and 7 W lamps had already disqualified themselves to participate at all according to the results of a pre-test displayed in Fig. ❹. Albeit, the light output efficiency with a tandem connection of two 9 W lamps on one magnetic ballast – and even an old, less efficient one – turned out equal to that of a high-end CFL and 20 % better than a cheap CFL from the DIY supermarket! It remains to be stated here that the operation of a CFL is always an operation with an (integrated) elec-



❼ **Two ballasts and one capacitor for operating four 18 W lamps (but four starters are required)**



❽ **Optimal wiring of the quadruple luninaire**

tronic ballast! So much about the better lamp efficiency with electronic ballasts. Compared to the single-mode operation of one 9 W TC-S lamp the 2 x 9 W tandem configuration turned out 25 % more efficient – with the same ballast, after all! However, the light output is a bit less than double that of the single lamp. This remains to be considered when designing a lighting installation.

2 The same lamp on different ballasts

But the tandem connection is also applicable to T8 lamps with a power rating of 18 W. Although in this case different ballasts are meant to be used for single and tandem configuration, the results are similarly profitable. Here, too, the finding is that the power loss in the class B1 ballast attributable to two lamps is even lower than that in the class B1 ballast for only one lamp (Fig. ❻). Specifically advantageous are those popular square luminaires that use four 18 W lamps (Fig. ❼ and ❾).

3 Different lamps of equal power ratings

Now there are some more lamp types with a rating of 18 W available on the market, e. g. the TC-D lamp, which has a much higher operational voltage drop and can therefore not be operated in tandem mode. But since the voltage drop across the lamp under normal operating conditions is greater, the voltage drop across the ballast is smaller. So the required reactive power rating of the ballast is also selected accordingly smaller (Fig. ❺) – and thereby the whole ballast is (Fig. ❽).

But this is not yet all. When the lamp voltage is greater, the lamp current is also smaller and reduces the required reactive power level again. Therefore a magnetic ballast for a TC-D lamp can be built extremely small, also when designed according to efficiency class B1 – even smaller than a commensurate electronic ballast (Fig. ❽)! So especially a luminaire with a TC-D lamp and a high-efficiency magnetic ballast saves space, production costs and energy in one go.

4 Light output measurements

The latter finds its confirmation when you add another light output measurement. For this reason the single and tandem operation modes of class B1 magnetic ballasts for 18 W and 2 x 18 W, respectively, were compared to a single and twin operation mode on an electronic class A2 ballast rated 18 W or 2 x 18 W, respectively. The result is compiled in 3 blocks of 7 measurements of the light flux Φ each, as displayed in table ❶:

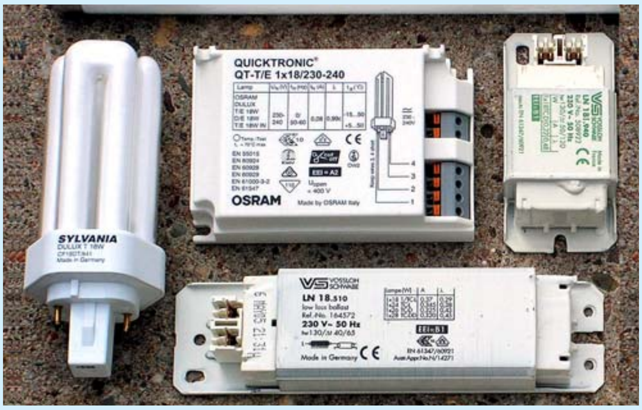
- One single T8 lamp,
- two T8 lamps in tandem or twin mode, respectively,
- one TC-D lamp,

with the following ballasts and data:

- Electronic ballast at the lower voltage tolerance limit 90 % (207 V),
- electronic ballast at rated voltage (230 V),
- electronic ballast at the upper voltage tolerance limit 110 % (253 V),
- magnetic ballast at the lower voltage tolerance limit 90 % (207 V),

Table ❶ Compilation of measuremets on 18 W fluorescent lamps with magnetic and electronic ballasts

Type (tested device)	Metering conditions	Measurements (DIAL) U [V]	P_{Tot} [W]	P_{Ball} [W]	P_{Lamp} [W]	I [A]	U_{Ball} [V]	U_{Lamp} [V]	Φ [lm]	Calculated values η_{Lamp} [lm/W]	η_{Tot} [lm/W]	S_{Tot} [VA]	Q_{Tot} [Var]	P_{Loss}/P_{Tot}
T8 lamp 18 W EB EEI = A2	$U = U_N$	207.0	19.10			98.4			1382		72.34	20.4	7.1	
		230.0	19.13			90.6			1381		72.19	20.8	8.3	
		253.0	19.10			85.0			1383		72.41	21.5	9.9	
T8 lamp 18 W MB EEI = B1	$U = U_N$ $\Phi_{MB} = \Phi_{EB}$	207.0	20.96	4.70	16.23	304.7	186.6	62.7	1195	73.65	57.03	63.1	59.5	22.4 %
		230.0	24.47	6.24	18.21	354.6	211.2	60.6	1320	72.50	53.95	81.6	77.8	25.5 %
		241.7	26.18	7.21	18.94	382.2	223.8	59.0	1381	72.91	52.75	92.4	88.6	27.5 %
		253.0	28.19	8.22	19.94	410.6	235.5	58.2	1438	72.13	51.02	103.9	100.0	29.2 %
T8 lamps 2 x 18 W EB EEI = A2	$U = U_N$	207.0	36.59			181.0			2816		76.96	37.5	8.1	
		230.0	36.58			164.2			2817		77.00	37.8	9.4	
		253.0	36.53			149.7			2815		77.07	37.9	10.0	
T8 lamps 2 x 18 W MB EEI = B1	$U = U_N$ $\Phi_{MB} = \Phi_{EB}$	207.0	33.70	3.33	30.37	296.0	146.9	62.2	2330	76.72	69.14	61.3	51.2	9.9 %
		230.0	42.24	5.34	36.90	379.0	179.2	58.6	2809	76.12	66.50	87.2	76.3	12.6 %
		230.8	42.70	5.58	37.12	387.0	180.9	57.9	2817	75.90	65.98	89.3	78.5	13.1 %
		253.0	50.48	8.20	42.28	437.0	208.7	54.5	3169	74.95	62.77	119.7	108.5	16.2 %
TC-D lamp 18 W EB EEI = A2		207.0	16.09			78.5			1064		66.13	16.2	2.3	
		230.0	17.75			78.2			1173		66.11	18.0	2.9	
		253.0	19.84			79.8			1276		64.34	20.2	3.7	
TC-D lamp 18 W MB EEI = B1	$U = U_N$ $\Phi_{MB} = \Phi_{EB}$	207.0	17.71	3.33	14.40	165.7	165.6	107.4	982	68.19	55.44	34.3	29.4	18.8 %
		230.0	21.69	4.96	16.70	204.7	195.1	101.7	1117	66.87	51.48	47.1	41.8	22.9 %
		241.4	23.86	6.01	17.80	225.7	208.9	99.0	1173	65.93	49.18	54.5	49.0	25.2 %
		253.0	26.53	7.48	19.05	250.5	222.4	96.5	1229	64.51	46.32	63.4	57.6	28.2 %



❾ TC-D lamp 18 W, energy efficient magnetic ballast and electronic ballast (top) for this and energy efficient magnetic ballast for commonplace T8 lamp of equal power rating (bottom)

- magnetic ballast at rated voltage (230 V),
- magnetic ballast at the upper voltage tolerance limit 110 % (253 V),
- magnetic ballast at the voltage magnitude where the light output equals that of the same lamp with an electronic ballast at 230 V.

5 Results

For measuring the T8 lamp in single-mode, a single-lamp electronic ballast was used instead of using the twin-mode one and connecting only one lamp, which would have been possible but would have yielded wrong results. The most crucial results can be found in table ❶, represented as the light efficiency η_{tot} in lumens per watt electrical power intake of the whole lamp and ballast system. The share of ballast losses in the total power intake can be given as a percentage – as done in the last column of the table. However, with the electronic ballasts the required measurement of the lamp power, the ballast output power to the lamp so to say, was not possible due to the high output frequency. Therefore the efficiency η_{Lamp} of the lamp alone could not be calculated. Nevertheless, the following results can be read and conclusions drawn from table ❶:

1. The advantages of the tandem configuration and of the TC-D lamp already found in the pre-measurement with respect to reactive power find their confirmation.

2. The magnetic ballast power loss increases highly over-proportionally to the systems operating voltage. At 253 V the power loss is usually double as high as at 207 V. Together with the slight increase of lamp efficiency η_{Lamp} the voltage reduction practice results as an efficient means of loss reduction for all magnetic ballast configurations.

3. Inversely as with 58 W lamps (see Section 5 of Chapter 1), the lamps are about 4 % brighter with electronic than with magnetic ballasts. With the twin electronic ballast compared to the magnetic tandem configuration the difference is even 8 %. The operating voltage on the tandem has to be turned up to 244 V before the same brightness as with the electronic twin ballast is achieved.

Therefore when assessing the light efficiency two different approaches have to be considered:

4. Either the luminaires are operated at rated voltage in either case. The comparison will then be closer to what will usually happen in practice, though it is not objective. We are then talking about a systems power of 19.13 W with electronic ballast versus a systems power of 24.47 W with magnetic ballast. A payback time for the well over 5 W saved cannot be given, as the impact of the price premium for an electronic ballast upon the price for a complete lighting installation is subject to substantial variances. However, with an energy price of 10 c/kWh it takes 1872 operating hours to save the first Euro. This cornerstone can be used for the according conversions: At 5 c/kWh it takes 3744 hours, at 20 c/kWh it takes 936 hours to save 1 Euro.

5. Or you calculate objectively. Nobody will increase the line voltage in order to achieve precisely the same brightness with the used/planned magnetic ballast as with the electronic ballast not used, but the lighting planner might include a few more lamps if the decision for magnetic ballasts has been taken. This would have practically the same effect as if the same number of lamps were connected to a line voltage of 241.7 V, which would be equivalent to the difference between 19.13 W and 26.18 W systems power, say 7 W. So the real, effective »savings cornerstone« is then 1418 operating hours per Euro saved at 10 c/kWh.

6. Moreover, it becomes obvious that the limits of the EU directive, which is 24 W systems power in class B1 and 19 W in class A2, are in principle not complied with, neither by the magnetic nor by the electronic ballast. Only by being rather lenient accounting to metering inaccuracy the EEI classes can still be seen as just about fulfilled.

But by all means this mode of operation does not represent the optimal combination. The power loss in a 36 W ballast is not double the loss in an 18 W ballast (»Paradox of the Big Ballast«), about the triple advantage of the tandem mode not even to speak. Rather, the respective conclusions to above items 4 to 6 for the twin or tandem modes of two 18 W lamps will be:

7. Comparing the operation at rated voltage in either case, the difference between magnetic and electronic ballast operation is now only more 2 W per system, whereas a system now comprises two lamps and one ballast (and two starters in the case of the magnetic ballast). So with an electricity price of 10 c/kWh it takes 5000 operating hours to save one Euro. Or, selecting a different example: At uninterrupted permanent duty with 8760 h/a and an electricity price which is usually quite inexpensive for such use, e. g. 5.7 c/kWh, the electronic ballast saves precisely one Euro per year.

8. With equivalent brightness, that is, assuming corrected voltage for the magnetic ballast (although, as mentioned earlier, hardly anybody will ever do this in practice) the difference is 6.6 W per system. With an electricity price of 10 c/kWh one saves one Euro in about 1500 operating hours.

9. Although the directive provides a separate line with limits for two lamps being operated on one ballast, the values per lamp are identical to those for the single-mode operations as under item 6. Very much unlike with the configuration described under item 6, however, the limits are by far kept here: The electronic ballast remains well over 1.5 W below the class A2 limit, the magnetic ballast even falls 3.5 W below the B1 limit.

On the TC-D lamp the following can be observed:

10. The efficiency is about 5 % to 10 % poorer than that of the T8 lamp. This may be due to the compact design which leads to a part of the light generated being absorbed by the lamp itself.

11. Here the use of the electronic ballast results in an uncommonly high saving of 28 % on equal voltage or 34 % at equal light output, respectively. It by far fulfils the requirements for class A2, while the magnetic one does not really match the limit for class B1. The magnetic one may have been designed a bit too small in favour of facilitating the design of very small luminaires (Fig. ❾ top right), and in electrical engineering skimping on active material (magnetic steel and copper) always comes at the price of reduced efficiency. It has to be considered, however, that these two measurements possibly cannot really be compared because they could not be carried out on the same lamp. The TC-D lamp for magnetic ballast operation is equipped with an integrated starter and therefore has only two connections (Fig. ❾). The starter is wired internally. The version for electronic ballast operation requires four pins.

12. Unlike the other electronic ballasts used in this test, the one for this lamp is not equipped with an electronic power stabilisation to offset variances of the input voltage.

4 Reactive power compensation of magnetic ballasts

Magnetic ballasts for fluorescent lamps cause high amounts of inductive reactive power, often even far exceeding the active share of the power. In industry and commerce this equals an obligation for compensation, which is a vintage technology, well known and neither sophisticated nor expensive. With fluorescent lamps, however, there are two different options to be assessed in the following.

1 General issues

Gases are generally not electrically conductive but may become so under certain conditions, just as any insulant becomes in a way conductive as soon as the breakdown voltage is exceeded. The voltage required to sustain the current flow in a gas drops as current increases. Ohm's Law seems to be perverted into its opposite. With some justification you could speak of a »negative resistance«, for the differential quotient du/di indeed is negative (Fig. ❶). This prohibits the direct application of the line voltage to any gas discharge lamp including fluorescent lamps, since either nothing will happen, or they will go bang. Some sort of current limiting device will have to be connected in between. The simplest approach would be to use an ohmic resistor, but this would drag down the efficiency close to the level of that of an incandescent lamp. Traditionally such lamps have always been operated on AC mains, so the second simplest approach is to use a reactor or choke, here called (magnetic) ballast.

2 Why compensate?

The power factor (for a lamp together with a magnetic ballast under normal operating conditions) is always indicated on a ballast (Fig. ❷). In fact a luminaire with a lamp rated 58 W and a magnetic ballast has an overall active power intake between 64 W and 70 W, so with the 0.67 A current rating the apparent power is around 160 VA and the reactive component some 144 var. So in the commercial and industrial sectors compensation becomes a must.

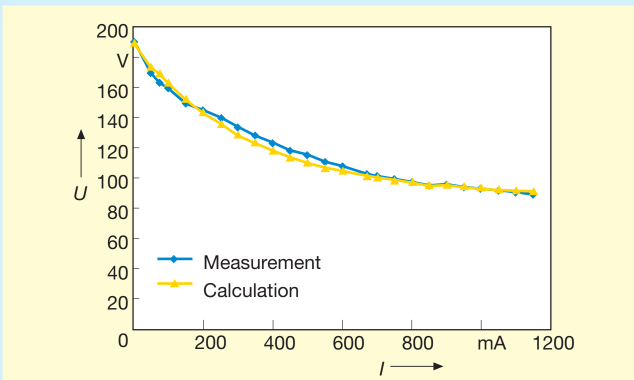
3 Disadvantages and risks

The argument commonly forwarded for compensating is cost reduction, while in fact, as a rule, only prices are considered, the price the utility charges for reactive energy metered at the point of common coupling, not the cost the reactive current causes on its way from the device consuming (active) power to the PCC. Not (yet) so with lighting. As an exception, it is really common practice with ballasts to compensate the reactive power right in the place of origin, where this is most effectively done, say within the luminaire. This may happen in the usual way by paralleling the (approximately) ohmic-inductive load by a capacitance. However, the disadvantages or risks are as with any other static VAR compensator today:

- Sound frequency signals in the mains, used for control of street lighting, night storage heating etc. may get lost.
- Capacitive reactance drops proportionally as frequency rises, so capacitors may be overloaded since there are a lot of harmonics and other frequencies in excess of the mains frequency rating superimposed upon the line voltage. On the left of Fig. ❸ the power intake of a small fluorescent lamp was recorded in an office environment without any compensation. The fundamental reactive power is really very high, with $\cos\varphi = 0.5$ – while it nearly equals the load factor *LF*, which means that the current is approximately sinusoidal, as becomes obvious also from the graph. So compensation becomes a must, but a parallel capacitor adds a tremendous lot of distortion, say higher frequency constituents, to the overall current (centre of Fig. ❸). Although the capacitance is properly dimensioned, the reactive current cannot be brought to zero. When nothing in the wiring is changed but just the inverter driven elevator in the building starts to operate, the distortion and thereby the reading of reactive power once again increases substantially (right of Fig. ❸). This provides evidence that indeed the additional current must consist of higher frequencies flowing through the capacitor.

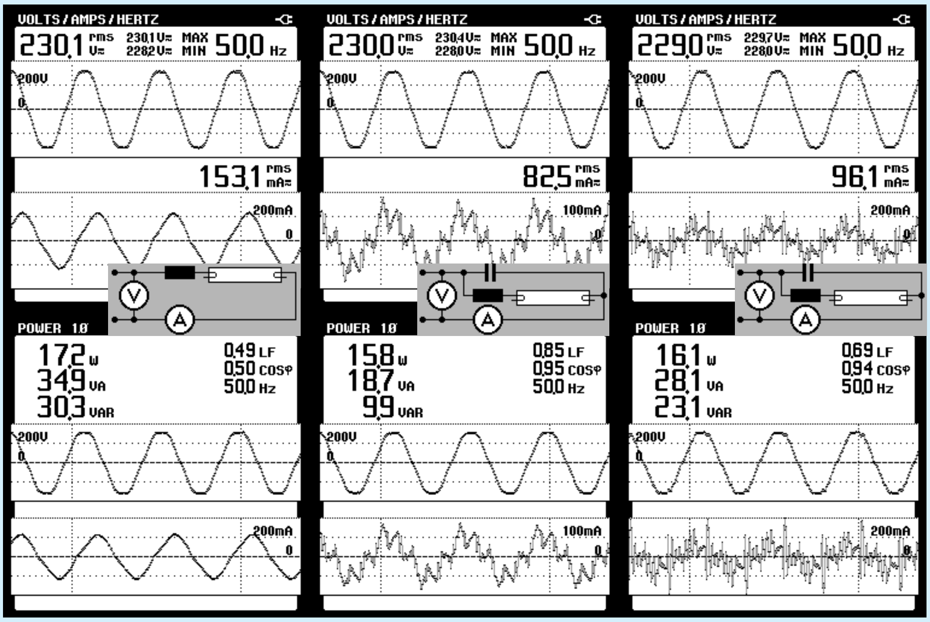
4 Serial compensation: Lead-lag circuit

Now in static VAR compensators the usual approach to cope with these phenomena is detuning the capacitors, say connecting them in series with a reactance that at mains frequency compensates (takes away) only a few percent of the capacitor's reactive power rating [7].
But why bother about an additional reactor with fluorescent lamps where a reactor is already there? Since current and phase angle with fluorescent lamps are practically invariable, there is another option, namely to use the ballast simultaneously for detuning a serial compensation capacitor (the so-called lead-lag connection, Fig. ❺). This means that every second lamp-and-ballast unit is (over-)compensated with a serial capacitor dimensioned – in theory – precisely in such a way as to make the current magnitude equal to that in an uncompensated lamp. The phase angle will then also be of the same absolute magnitude but with opposite sign.
So all the disadvantages of parallel compensation are avoided. Also the stroboscope effect is minimised through the phase shift between the leading and the lagging circuits usually installed within one luminaire. This is the reason why most luminaires come with 2 lamps. As a side effect, the compensated share of the

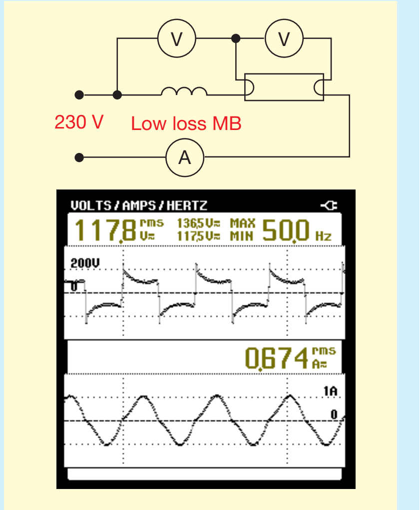


❶ Behaviour of a 58 W fluorescent lamp that is connected to a d.c. supply

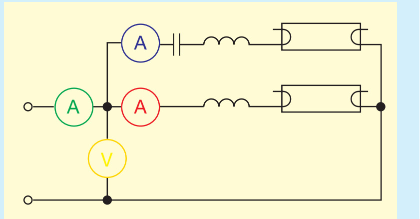
❷ The power factor is always indicated on a ballast



❸ **An 11 W fluorescent lamp with magnetic ballast without compensation (left) and with parallel compensation (centre and right)**



❹ **Voltage across a 58 W fluorescent lamp and current in the lamp**



❺ **Lead-lag compensation**

lamps are much less sensitive to voltage variances and flicker (Fig. ❼) and entirely insensitive to possible direct voltages superimposed upon the feeding voltage, which otherwise, even if minimal in magnitude, may heavily affect inductive components.

5 Disadvantages of lead-lag compensation

The only disadvantage of this compensation principle is the risk to dimension the capacitor wrong. A bit of over- or under-compensation does not matter much in parallel, but in serial it means more than that (Fig. ❽, Fig. ❾)! It means wrong lamp current, possibly lamp, capacitor and ballast overload or at least either higher loss level than necessary and premature failure or reduced light output. Therefore the tolerance rating of these capacitors is rather narrow, just 2 %. Care has to be taken with the selection of replacement, which should not be a problem, since the correct capacitance for serial compensation always used to be indicated on a magnetic ballast (Fig. ❷), but yet sometimes errors occur. Now that German lighting industry has decided to abandon serial compensation (instead of adapting the capacitance ratings to adequate values, which would be feasible without any risk, as both measurements and magnetic ballast experts confirm), the capacitance ratings on the rating plate (still to be found on the ballasts in Fig. ❷) are now omitted.

Another disadvantage – not of the principle but in common practice – is that the currents with and without serial compensation are not really equal. The ratings differ depending on whether inductive or capacitive coupling is applied (Fig. ❷). At the rated current of a 58 W lamp, which is 0.67 A, the inductance of a 230 V 50 Hz ballast turns out to be 878 mH. This requires a capacitance of 5.7 µF to end up with a resonance frequency of 70.7 Hz, at which theoretically the lamp current magnitude at 50 Hz would be equal with and without the serial capacitor.

Yet, for some reason, possibly the extreme distortion of the voltage across the lamp (Fig. ❶) or non-linearity of the ballast, currents turn out unequal. As a standard, 5.3 µF or 5.2 µF are used (Fig. ❷) but this still by far does not offset the difference. A measurement (Fig. ❹) shows that 4.6 µF would be the correct value but it is argued this could not be used in order to avoid starting problems with the lamps, especially in cases of undervoltage and extremely low temperatures. It has nothing to do with the principle as such, once the lamp has been fired successfully, and the firing problems could very well be overcome by the use of electronic starters, which are the better choice anyway (Chapter 5 and [2]). Moreover, the question is whether there is any reason to worry at all. Rather, a further test revealed that absolutely no starting difficulties are to be expected: 3 electronic starters as well as 2 very old worn-out glow starters were tested together with 2 different types of 58 W lamps, both from the same manufacturer but of different light colour, with a modern efficient magnetic 230 V ballast. **Both** the **reduced 4.6 µF serial capacitance and reduced voltage** were applied, and all combinations started without any problems at first attempt with only 180 V, with just two exceptions where successful firing occurred »only« at 190 V. So it seems a revision of capacitance ratings is due here but industry rather seems to be hoping to replace all magnetic ballasts with electronic ones in the long run and therefore appears not too ambitious to adapt any old standards to new technologies as long as either of these refer to magnetic ballasts. However, even if the impression roused among experts may cause a different feeling, approximately 70 % of the market is still being held by magnetics. In some countries the ratio is even a lot more extreme (Spain 91 % magnetic ones). At least in terms of sold pieces this is so. In terms of turnover figures the share is only more around 50 %, due to the much higher added value. Or should we rather speak of higher added price in this case? Howsoever, it is understandable that the lamp and luminaire industry is much keener on the promotion of electronic ballasts. For reasons of justice, however, it also needs mentioning that electronic ballasts more often than magnetic ones provide the option of operating 2 lamps on 1 ballast.

6 Central compensation

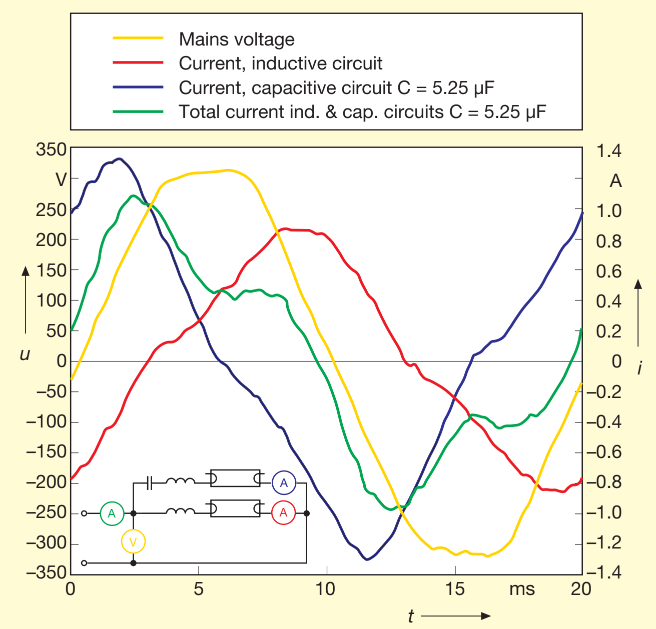
If the attitude of ZVEI and hence parallel compensation make their way, this will inevitably foster a tendency towards centralized compensation because 1 capacitor rated 520 µF is cheaper (of purchase price) than 100 pieces of 5.2 µF each – whereas »cheap« only means »cheap« here and not »cost efficient«, for this approach only sees the price for the reactive power counted on the electricity counter and not the losses and adverse effects the reactive power imposes upon the system behind the counter on its way from its source (the luminaire) to the sink (the capacitor bank). Adding to this, the parallel capacitors may lead to the problems described before, and these repercussions then tend to be allocated to the magnetic ballast, which in fact are totally innocent here. It also remains an open question whether the central compensation unit will be switched off the very moment the light is switched off, otherwise it will turn into the very opposite of what it is meant to be and will **generate** additional reactive power rather than to **offset** it. In the case of decentralized compensation, which the lead-lag compensation inherently and compellingly is, this option does not arise.

7 Improving the power factors with small lamps

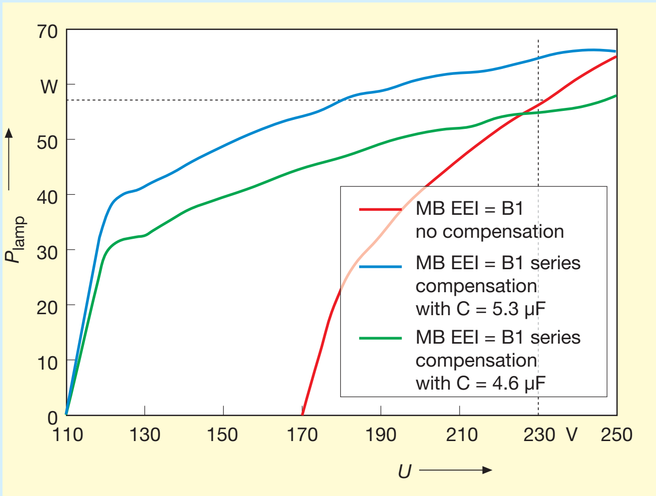
The lamp voltage across smaller, i. e. shorter fluorescent lamps of the same type family is lower than with the longer types of the same series. Thereby a larger part of the voltage drops across the ballast, and this voltage drop is greatly – in the ideal case would be wholly – inductive. So on the one hand the smaller lamp has a lower active power intake, but on the other hand it has a higher reactive power dissipation.

Commonly, these two effects lead to a substantially lower power factor for the lower lamp power rating. So the compensation investment increases inappropriately. This can be observed very clearly on TC-S lamps with 5 W, 7 W, 9 W and 11 W power rating, since these 4 models are all operated on the same ballast.

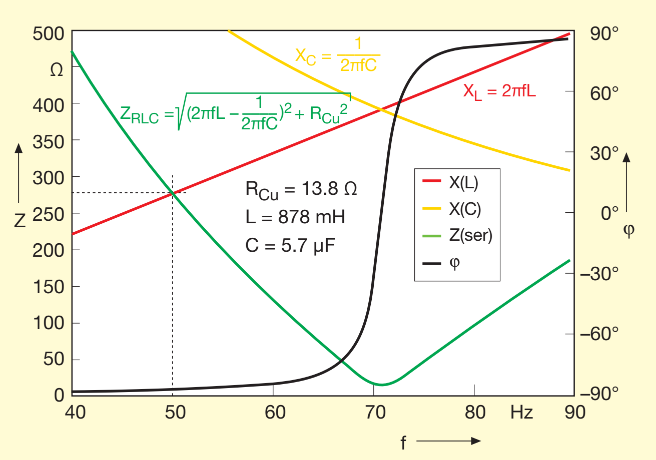
However, the lamp voltage across the TC-S lamps rated 5 W, 7 W and 9 W is so low that the common mains voltage of 230 V allows two of these lamps to be operated in series on one ballast. In effect, this doubles the lamp voltage again, of course. Since the same ballast is used for this so-called tandem connection as for the single operation, the actual current when operated in tandem lies slightly below the lamp current rating – though not very much, since the inductive voltage drop still prevails. One of the advantages of this operating mode is that **two lamps together** use **less reactive power** than one of them already does in single mode. But the tandem configuration may very well claim even more advantages than this (see Section 3).



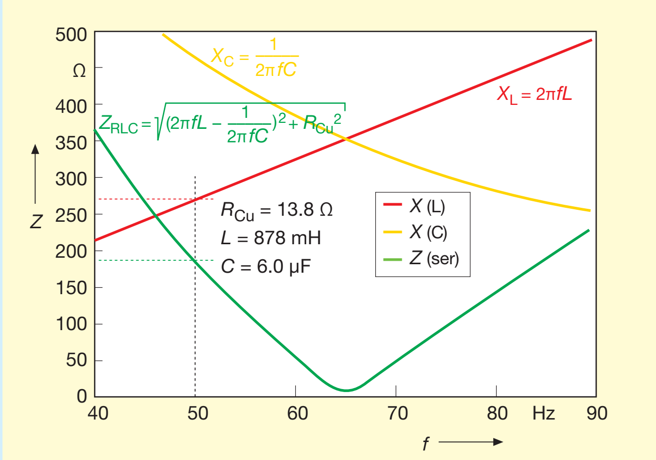
◀ ❻ **Duo connection of 2 fluorescent lamps with class B1 magnetic ballasts at rated voltage (230 V) and rated capacitance (5.25 µF)**



❼ **Much better resilience to voltage variances with serial compensation**



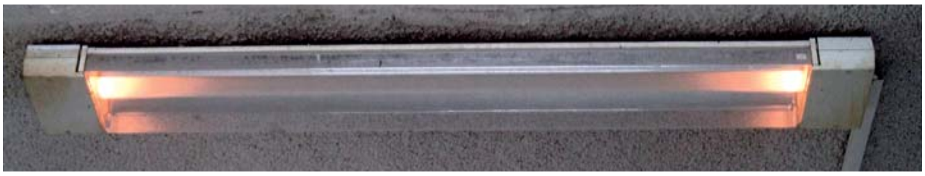
❽ **Correct dimensioning of serial compensation capacitance**



❾ **Serial compensation capacitance dimensioned 20 % wrong: Lamp, ballast and capacitor current 45 % too high!**

5 Electronic starters for fluorescent lamps

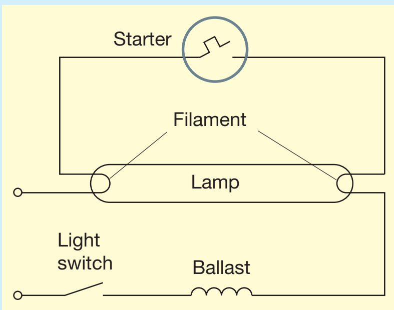
When a fluorescent lighting tube reaches the end of its usable lifetime, vain starting efforts will give rise to haunting flashes and flicker for a day or a week. Finally the starter fails, its contacts would weld together and leave the lamp in a useless, but still energy consuming state (Fig. ❶). Electronic ballasts are able to identify the end of the lamp life and hence to switch the lamp off, but their replacement for magnetic ballasts incurs higher costs, while their lifetime expectancy is much lower and the conversion is more sophisticated. It is easier and more cost-efficient to replace the generic glow starter with an electronic starter and leave the magnetic ballast as it is.



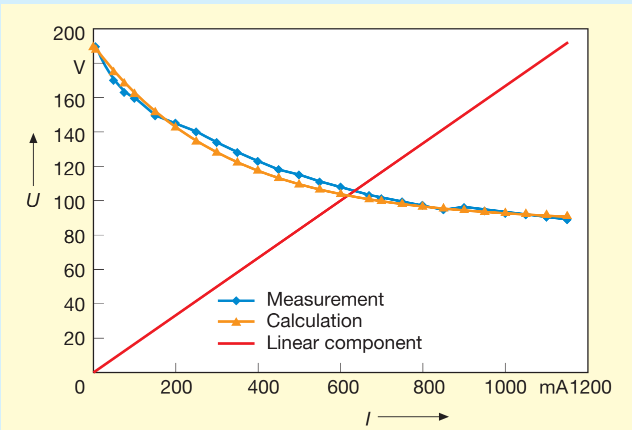
1 The working principle of a fluorescent lamp

The basic wiring of a fluorescent lamp with a magnetic ballast is given in Fig. ❷. The ballast has two different functions in this configuration. For one, it has to limit the current, which otherwise would increase instantaneously due to an avalanche effect (Fig. ❸, also see Section 1 of Chapter 4). But this is already the second stage of the operation. Due to said physical characteristic it is not so easy to get the current going at all. When commonplace line voltage, 230 V 50 Hz or something similar, is applied to a fluorescent lighting tube, normally nothing will happen. The withstand voltage of the gas inside, usually low pressure mercury vapour, 1.3 mg in a 58 W tube, is higher. When the filaments are being heated, they start to emit additional electrons, but this still does not suffice to reduce the breakdown voltage below the regular periodic peaks of the mains alternating voltage.
With a cold 8 W T5 type lamp (room temperature) self-ignition without any sort of firing was observed at 480 V TRMS ($\geqslant$680 V peak). This value could be reduced to 380 V by pre-heating the filaments with a separate transformer. A 58 W tube was found to start off from the cold state at 1300 V sine wave, dropping to 550 V with pre-heated filaments. A further reduction occurs when the voltage is applied abruptly, from 0 to full, instead of slowly increasing it by means of a variable transformer, but still self-start at 230 V 50 Hz does not occur. Therefore a starter is connected in parallel with the lamp. When applying the mains voltage a glow discharge is initiated inside the glow starter (Fig. ❹a and Fig. ❺a) which heats up the bimetallic contacts and causes them to close (Fig. ❹b and Fig. ❺b). Now current flows from the mains via the ballast, the cathode filament, the starter and the second filament. This way the cathodes are pre-heated. But since the glow discharge has solely been shorted by the bimetallic contact, this contact now cools down and opens again a few seconds after closing. By interrupting the current through the (relatively great) inductance of the ballast a substantial voltage surge is generated across the ends of the fluorescent lamp, starting a current flow through the tube (Fig. ❹c and Fig. ❺c) – at least this is what you hope.

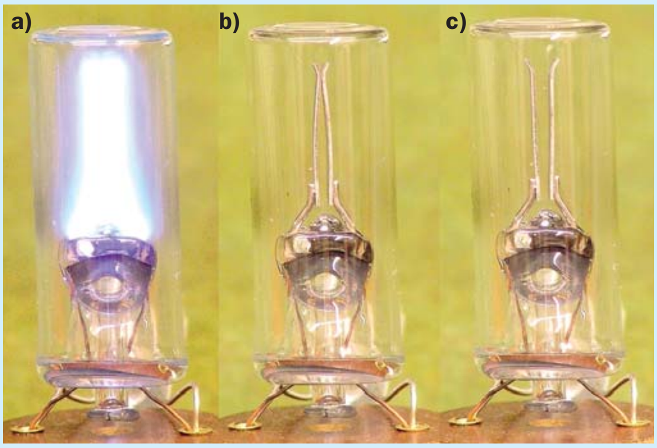
In fact the luminaire is fed with alternating current, and whether the instantaneous current value at the instance of ignition, that is, of contact opening, is high enough right at that moment to generate a sufficiently high voltage impulse is an open question. But not now does not mean never ever. Since now, if the strike is not successful, the full voltage comes to be applied across the starter's terminals, glow discharge starts again, and a few seconds later the next firing attempt follows and so on until some very fine second the instant of firing coincides with sufficient instantaneous current amplitude. Only then a small current flow through the lamp is initiated which immediately generates more charge carriers so that the avalanche effect of conductivity increase according to Fig. ❸ of the gas inside the tube is started. The ballast's inductive resistance (reactance) now prevents that on account of this conductivity increase also the current increases with avalanche effect right up to the big bang. The voltage across the starter, which at any instance is identical with the voltage drop across the lamp, is now small enough so that no new glow discharge is initiated in it. At least preliminarily this is so. As the lamp ages, the lamp voltage gradually increases until at some moment it is so high that glow discharge inside the starter does start again (re-closing voltage): The starter is triggered even though the lamp is still in operation and shorts it out. Thereby the lamp is turned off – and of course it is ignited right again. There you have your flashing thunderstorm.
During pre-heating, the current exceeds the rated lamp current by about 35 %, since it flows only through the reactor (Fig. ❺b) – and also through both of the filaments so as to pre-heat them. Their voltage drop, however, is low, only some 10 V, while the great voltage drop across the lamp is shorted out.
So statistically, this primitive, incredible technique called glow starter replaces any one start of a given lamp with several starting attempts, while especially the number of ignitions is reported to be a crucial lamp ageing factor. In fact, a company manufacturing both magnetic and electronic ballasts assigned the



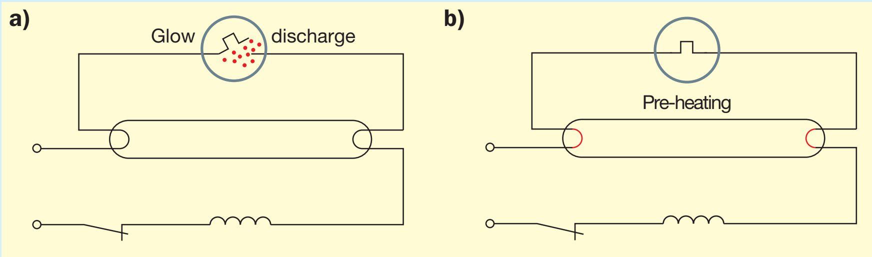
❷ Wiring diagram of a fluorescent lamp with magnetic ballast and glow starter

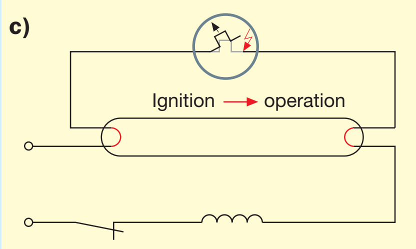


❸ Behaviour of a 58 W fluorescent lamp connected to a d.c. supply



❹ Glow starter during a starting process:
a) Voltage is applied and bi-metallic contact glows;
b) contact closes due to heating;
c) glow discharge ceases, contact cools down and opens





❺ Principle of the ignition process
a) voltage applied;
b) current pre-heats cathodes;
c) starter contact opens and self-induction pulse in the ballasts ignites the lamp – hopefully

designation »deliberately loose contact« to this unspeakable technique. Nevertheless it is exactly these that are used in lifetime test procedures of fluorescent lamps, the results of which are proudly presented to the public as featuring a 30 % to 40 % longer lamp life with electronic ballasts (as far as these are provided with filament preheating, which **with electronic ballasts** does **not** come by default – see Section 1 of Chapter 1)! This result could as well be achieved with electronic starters. With an old poor quality ballast that obviously operated way too close to the range of magnetic saturation, if not right within, the current during cathode heat-up rises clearly more than mentioned 35 % above the rated 0.67 A, namely as high as 1.15 A. The heating power of each filament reaches 13.5 W, which makes the filaments shine in a bright white even without any voltage between the two of them applied. This provides more likelihood to get started because the instantaneous current amplitude at the instance of contact opening is more likely to exceed the necessary minimum for ignition, which then also lies lower because there are plenty of free electrons emitted. Unfortunately it also adds to the ageing impact of start-ups if current is really excessive, while pre-heating is basically essential to reduce the wear effect of starting procedures. The much better choice is a combination with an energy efficient ballast, which by design operates still more or less within the linear range of the core material even during pre-heat, and an electronic starter. Electronic starters have the following advantages:

- Start after optimum pre-heat time for maximum lamp life.
- Start at a defined point of the phase (current peak), so each firing is successful, no flickering.
- No replacement of starters, unlike recommended to do or even required (Fig. ❾) with conventional glow starters along with each lamp replacement.
- No residual current through the filtering capacitor as contained in a conventional glow starter.

2 Improved glow starters

Improved glow starters (Fig. ❻) already provide a 20 % lifetime expectancy increase, but of course the glow technology cannot offer any of the other advantages of electronic starters (Fig. ❼). All the more amazing it does appear, though, that this polished-up version is being offered by an international lamp and electronics producer, unlike electronic starters, as one should have expected. Howsoever, it makes the lamp lifetime advantage of electronic ballasts dwindle away to some 10 % or 20 %.

3 Electronic starters

It would lead too far here to delve into the electronic details of such starters (Fig. ❽) at this point. The working principle, after all, is the same as with conventional ones: A normally closed contact that opens a certain time lag after powering. As a comparison the starting procedure was recorded with the transients recording function of a power analyzer (Fig. ❿), more precisely speaking the voltage across the ends of the lighting tube was recorded. So the voltage input terminals of the meter were connected to the poles of the starter, which are permanently connected to one of the filaments each. The results were pretty unambiguous:
When turning the system on with a glow starter, 6 transients were recorded in total (a mean value – between 1 and 13 recordings were taken during a series of attempts, for glow starters play a game of lottery with the lamp and ballast). In Fig. ❿, Transient 1, you first of all recognize the sine voltage across the terminals of the not yet burning lamp and subsequently the closing of the supplementary switch. Obviously its contact bounces and causes a self-induction impulse in the ballast, triggering the meter.
In Transient 2 apparently nothing has happened. In fact a firing process did very well occur, but the transient was minute, since the starter contact opened very close to the current zero crossing. The meter's trigger threshold had already been stepped down at that instance because there had not been any voltage across the input terminals for about half a second, since the starter had already been idling in preheat state with its contact closed. Therefore the trigger threshold had already dropped from 200 % of 500 V to 200 % of 4 V. As the display scale does not step down as soon as the one for the trigger threshold does but would rather have followed only several seconds later, this scale continues to be 500 V/div. For this reason the self induction pulse which was very low in this case cannot be seen in the screenshot but still sufficed for triggering this shot. In fact a noise could be heard inside the starter at the instance of this shot, verifying that any activity was going on inside.
In Transient 3 the procedure of Transient 1 repeats. Here the meter obviously registers the closing of the contacts because they bounce but missed the actual firing attempt, possibly because it struck precisely the current zero crossing. In Transient 4 the procedures of Transient 2 repeat.
In Transient 5 it is obvious that the starter contact has opened for barely 2 periods of the

mains frequency. Again the lamp was not fired, as can be seen from the sinusoidal voltage wave shape in the time section between opening and closing. It has to be doubted that this thermo-mechanically operating component has realized within such a short time span that the firing was not successful and that it has even drawn the right consequences from this and closed the contact again. Rather, it has to be assumed that the contact re-closing would also have occurred if the lamp had been fired successfully, and that the success had thus been made void. This would explain the frequent flashings of fluorescent lamps when fired with such starters. Apart from this it would have been next to a miracle, had this attempt been successful, since at the instance of contact opening as well as of closing a heavy oscillation can be observed, absorbing a substantial share of the energy needed for firing – and dissipating a large part of it as radiated disturbance. Probably the contacts just opened too slowly, so that the energy stored in the ballast discharged between the two of them instead of doing so inside the lamp.

In Transient 6 the approach of trial and error – he who searcheth findeth – has finally been successful, placing a clean self-induction pulse close to the current peak, and the lamp goes into operation. This becomes clear from the typical voltage waveform across the lamp electrodes that shows up on the right side of the ignition impulse.

It has to be seen as quite peculiar, however, that none of the impulses really starts at the time zero line but a few milliseconds later. There must be some latent pre-impulses present, which do not become visible in the diagrams but act as trigger signals. Once again, this underlines the dirtiness of impulses generated in this way.

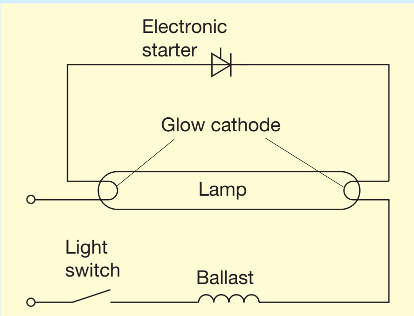
Fig. ⓫, however, provides evidence of how clean such a starting process can be and always will be using an electronic starter. You can take this recording as often as you like, and it will always look alike: There is a high, narrow peak at a precisely defined point of time. For this reason this recording is displayed twice – these are two different views of the same event. In the lower view the cursor line was merely moved to the right. This provides the advantage of making the very narrow peak visible at all, whenever it is difficult, since it is very high but extremely narrow, just as it is supposed to be. The left view, on the other hand, provides the opportunity to read (at the top of the screen) that the impulse ranges from –0.32 kV to 1.36 kV. That's enough – and quite sure causes less conducted and radiated disturbances than the multitude of blurred impulses of the glow starter.

4 Summary

While the number of starts counts as a crucial ageing factor for the lamp, the generic glow starter as well as »improved glow starters« replace one starting process with several starting attempts. Hence it is no miracle that a 35 % lifetime expansion is given for the same lamp when operated with an electronic rather than with a magnetic ballast. While this is common practice, it compares the poorest magnetic technology, a generic glow starter, to

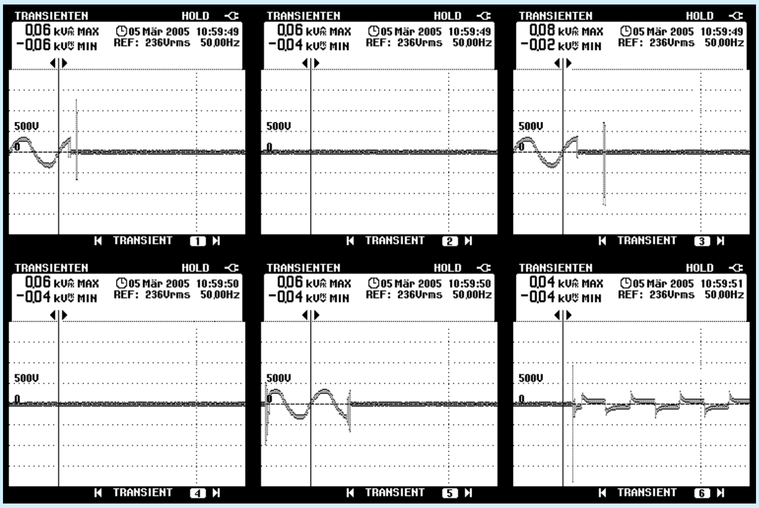
❻ **Glow starters, among these 2 »safety glow starters« (right side)**

❼ **Electronic starters are available for any operating situation**

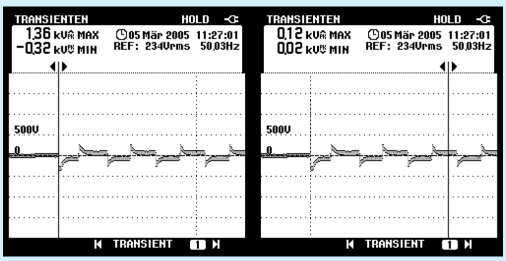


❽ **Working principle of an electronic starter**

❾ **The inside of a glow starter**
left: used; right: new with filtering capacitor



▲ ❿ **Starting a T8 lamp 58 W with a conventional starter**



⓫ **Starting a T8 lamp 58 W with an electronic starter** the best practice of the electronic technology, the warm start. On top of this the warm start does not come by default with an electronic ballast but rather at an extra price premium – while inevitably being an integral function of a magnetic system. While an electronic ballast always starts the lamp successfully at the first attempt, this advantage is also available at a much lower cost by using electronic starters. This is the first part of the electronic starter's contribution to a longer lamp life.

Electronic starters are not cheap, but cost efficient. At a rate below 3 Euros per piece in lots around 100 pieces you cannot either call them really expensive. For greater lots you get the usual rebates, about 2 Euros at 1000 pieces. Ecological advantages arise from the very low need for replacements and the longer lamp lives: Once the reclosing voltage is reached and the flashing thunderstorm starts, one only needs to replace the glow starter with an electronic one, and the apparently worn out lamp will function again, possibly for quite a while. This explains the second part of the lamp life expansion.

For glow starters, however, a replacement along with every lamp replacement is recommended for some good reason, and after the state of Fig. ❶ is reached it even becomes inevitable. This needs to happen only three to five times, and right away the electronic starter is cheaper than the common one – calculated alone with the procurement of spares. Including the labour costs, the conversion to electronic starters will pay off already by the first replacement. The electronic starter has an extremely long life and survives the lifespan of the whole luminaire. The failure rate is extremely low. Exceptions are cheap counterfeits from the DIY sector, destroying the good reputation of a product, as often is the case. In several cases such products dreadfully failed some compliance tests with current standards carried out by VDE, while on the original the test was aborted after 100,000 successful ignitions at the end of the testers' patience. The 5 »safety« glow starters, which these were being compared to, failed after between 28,000 and 32,000 starts, all of them being exposed to a standard test cycle of 20 s »on« and 40 s »off« with a 58 W lamp and a magnetic ballast EEI = B2. 5 generic glow starters by a different fabricator survived this test between 43,000 and 69,000 times [8]. One difficulty of electronic starters is electricians' limited awareness of their existence, for which reason they are often not identified and are thrown away when replacing a lamp on account of above mentioned recommendation or just routine. This is unfortunate. However, if staff is adequately trained the abandoned need for replacements is only the beginning of the savings. Next, the longer lamp life takes effect.

Hence, the electronic starter provides a magnetic ballast with all of the advantages that are normally allocated to electronic ballasts only, except the energy saving. The electronic starter does not save any energy during the lamp's normal operation, since it is inactive then, but it does become an energy saver when the lamp comes to the end of its life and is switched off instead of being kept in a state that does not only harass residents, stress the ballast but also consumes approximately as much power as a functioning lamp does. As for the energy saving potential, the other 5 chapters of this brochure should have clarified that the potential of magnetic ballasts is largely under-estimated, so together with an electronic starter they may serve nearly all sectors of the market just as well, with the exception of dimming techniques, but with a much sturdier solution at a lower price. ■

6 Light output measurements on T5 and T8 fluorescent lamps

As nearly all experts of lighting, electrical engineering and facility management know, only the combination of modern T5 fluorescent lamps with automatic dimming techniques can offer the best opportunities for energy saving in the lighting sector. Just a small group of specialists remains sceptical about these claims.

Reports about new lighting systems and renovations of lighting installations regularly quote the »new more efficient T5 lamps«, as if it went without saying that the efficiency of a T5 lamp is by default higher than that of a T8 lamp. Albeit, a look at the catalogue data already reveals that this, if at all, only applies to the so-called T5HE lamps optimized for High Efficiency. Those classified T5HO, optimized for High Output, perform significantly poorer than a commonplace triphosphor T8 lamp (table ❶). In the cases of electronic ballasts the input power and light output remains stable independently of the input voltage, while the input power to a magnetic ballast system of course varies greatly with input voltage. So a point can be found (at 217 V) where the measured lamp power in a 58 W T8 lamp driven by a magnetic ballast is exactly 49 W and thereby matches the rating of an existing T5 lamp with a light output of 4300 lm. But at this point, namely of equal power inputs to the T5 and T8 lamps, the light output of the T8 lamp is already ≈ 4600 lm – even though it was operated at mains frequency here and the T5 lamp, of course, at high frequency, as specified. This casts serious doubts over the practical effect of the theoretical efficiency improvement at high frequency operation. Or over the »more efficient T5 lamps«. Or both.

1 New EU Directive

Due to the curious fact mentioned earlier that the Directive allows higher losses in an electronic ballast than in a magnetic one, e. g. a 54 W T5 lamp with a class A3 ballast may have a systems power of 63 W (table ❶, of Chapter 2 in this booklet), yielding a ballast loss share of 14.3 %, while the magnetic B1 system with a 58 W lamp – formally and officially – must not exceed 64 W and is thereby limited to a loss share of 9.4 %. But it was also mentioned there that in practice the lamp power with a magnetic ballast is found to be only between 53.5 W and 54.5 W (table ❶, of the Chapter »New EU Directive for not quite new ballasts« in this booklet), and that in the end of a day the systems power is crucial and not its split across lamp and ballast. Howso-ever, through the theoretical or the practical approach, the T5 lamp hits a tough challenge to match the expectation to provide a better efficiency than a good T8 magnetic system has. On top of this, the unfortunate fact that in one system the rated light output is reached more or less around the rated power intake and in the other one even far below, both catalogue data and the Directive yield unrealistic payback times.

Unfortunately this will never be discovered, since the electricity consumption of the lighting installation is not registered separately and because during a renovation a new system will always replace an over-aged one which is insufficient in all respects. Never ever will e. g. an optimized modern magnetic system be replaced with an optimized modern electronic system. So the energy savings remain a matter of belief and trust in what the specifier specifies.

2 Measurements at full and dimmed power level

So if you want to save energy you will try to reduce the lighting level automatically, dependent on the level of available daylight. As you have learned in Section 4 of Chapter 1 in this booklet, the reduction of the voltage fed into magnetic ballasts, although it does save energy, does not reach out far enough to call it a »dimming technique«, so you will try with dimmable electronic ballasts. But again, the question was how far the savings potential would go.

Measurements were commissioned with an independent certified lighting laboratory [6] by the German Copper Institute DKI [9] and the company M&R Multitronik [10] to complement the existing measurements on magnetic ballasts. In order to obtain objective, comparable results compliant with the existing measurements reported in Section 4 of Chapter 1, a twin electronic ballast together with two commonplace, readily available T5 lamps (triphosphor, colour rendering index 840) were used, since it has turned out in Section 2 of the same chapter that a twin electronic ballast usually has lower losses than two single-lamp ones. As for the lamps, the lowest wattage of the biggest available size (1449 mm) was chosen because the greatest efficiency could be expected from these. This led to a rating of 2 * 35 W.

The T8 lamps had been tested before with an ambient temperature of 25 °C according to the standard [11] where they usually perform their best efficacy. The T5 lamps were additionally measured with an ambient temperature of 35 °C, deviating from the standard, since for some good reasons they are optimized to this ambient temperature.

The results were summarized in Fig. ❶, where the systems' light outputs were plotted against the respective electrical power intake. Furthermore, a line was included in this plot, representing a constant efficacy of η = 80 lm/W, which should represent a guideline for the efficiency in today's lighting installations. In this way the following becomes evident:

- The efficacy of any T8 system increases during input power reduction. Generally speaking, the values in the lower segment lie above the 80 lm/W »guideline«, while in the upper half they lie below and strongly tend to flatten out, especially in the overload range.
- The T5 lamps exhibit the inverse behaviour: Efficiency decreases during dimming. Values in the upper range tend to lie above the »guideline«, while values in the lower range will rather lie below.
- The improved efficiencies of the T5 lamps at 35 °C against the values measured at 25 °C become quite obvious.

3 Assessment of the measurement results

Unfortunately this type of plot (Fig. ❶) is not very adequate for a direct comparison of either system against the other one because there are not any two lamps T5 and T8 with equal electrical power ratings available. It was therefore successfully tried to find a different method to compare both of the systems to each other by plotting the light efficacy against the relative system power (Fig. ❷). In this type of graph a direct comparison of different systems should be possible when keeping the following remarks in mind:

- For the T8 systems, what is meant by relative systems power is the ratio of the measured systems power at the respective voltage divided by the systems power measured at rated voltage of the same system (for instance, with the old magnetic ballast class EEI = C the reference point representing 100 % is 69 W, that of an improved magnetic ballast EEI = B1 is 61.4 W, which represent the respective systems values measured at 230 V).
- For the T5 system, what is meant by relative systems power is the ratio of the measured systems power at the respective dimming level divided by the systems power measured when set to full light output (100 %, i. e. the same system with dimmer set to full power, the supplying voltage always equalling 230 V).
- For ease of orientation, the minimum requirements for class A1 are plotted in the chart in stroke-dotted lines once for a reference ambient temperature of 25 °C and once for 35 °C.
- The non-dimmable electronic ballast also included in the measurements could not reasonably be displayed in this format, since its power intake, along with the light output, is invariable and would have yielded only a dot.

Hence, the above description facilitates the following observations:

- The T5 system under test by far exceeds the minimum requirements.
- It becomes even clearer now that the efficacy of the T8 system increases due to power reduction (and accordingly drops inadequately in the overload range), while the efficacy of the T5 system is best at full power and drops during dimming.
- At full load and 25 °C ambient temperature the T5 system is about equally efficient as the best T8 magnetic system (EEI = B1).
- At full load and 35 °C ambient temperature the T5 system is ≈ 10 % more efficient than the best T8 magnetic system is at 25 °C.
- At ≈ 75 % of their respective electrical power input measured at 230 V or of the undimmed lamp, respectively, the efficacy of the best T8 magnetic system is about equal to that of the T5 system at 35 °C.
- When reducing, respectively dimming, the systems power to ≈ 60 %, the efficacy of the T5 system even drops below that of a T8 system with an ancient class D magnetic ballast which was retrieved from a scrap metal container back around 1986.
- When reducing to ≈ 50 % input power the possible range of application for the voltage reduction technique ends. Otherwise the lamps will go out completely. A greater dimming range can be implemented with dimmable electronic ballasts only.

Table ❶ Catalogue data of T5 lamps with electronic ballasts compared to the measured data of T8 lamps with magnetic ballasts described in detail in Section 4 of Chapter 4 in this booklet

Lamp	T5 HE	T8 (measured values)			T5 HO (catalogue data)	
Length	1449 mm	1500 mm			1449 mm	
Power rating	35 W	58 W			49 W	80 W
operated with	Electr. b. (HF)	Magnetic ballast (50 Hz)			Electronic ballast (HF)	
Rated system power	42 W (A3) 39 W (A2)	– –	67 W (B2) 64 W (B1)	– –	58 W (A3) 55 W (A2)	92 W (A3) 88 W (A2)
Measured lamp power	–	49 W	53 W	58 W	–	–
Measured system power	37 W (A1)	55 W	61 W	69 W	–	–
System voltage	207…253 V	217 V	230 V	244 V	207…235 V	207…235 V
Light flux	3300 lm	4596 lm	4951 lm	5305 lm	4300 lm	6150 lm
System light efficacy	79 lm/W (A3) 85 lm/W (A2)	84 lm/W (B1)	81 lm/W B1)	77 lm/W (B1)	74 lm/W (A3) 78 lm/W (A2)	67 lm/W (A3) 70 lm/W (A2)

4 Final conclusions

- Dimmable ballasts provide only a rather limited energy savings potential. Who wants to save energy should reasonably employ a combination of voltage reduction and subsequent grouped automatic switching (e. g. from the aisle side to the window side in an office) after exploiting the (limited) »dimming« potential of voltage reduction – optionally, wherever possible, applying a technique which comes without any need for stand-by consumption [12] and using electronic starters (see Section 5 of this chapter), which spare on the lamp life as well as on the employees' nerves wherever switching occurs more frequently than once a day.

- The voltage reduction technique is no replacement for dimming. Who wants to dim has to use dimmable electronic ballasts. On the background of today's knowledge all techniques for dimming magnetic ballasts that have ever been around are makeshift solutions and do not satisfy modern needs. They should therefore not be considered any longer.

5 Make sure not to replace losses with losses

Still, these considerations do not yet include the following circumstance:
Dimmed operation of fluorescent lamps represents permanent cathode heating operation. The position »Lights off« is usually identical with the position »Dimmed down to 0«. Unless care is taken that the supply voltage to the lighting installation is shut off after work and on weekends, the lamps continue to be operated in a »Dimmed down to 0« state. This sabotages the underlying endeavours to save energy. E. g. with the following assumptions:

- On a T8 lamp rated 58 W (whose systems power is 59 W in class A3 or A1, respectively) a power saving of 55.8 W be possible (»Dimmed down to 0« with a residual consumption of 3.2 W – see Fig. ❷ of Chapter 1 »Magnetic ballasts for fluorescent lighting« in this booklet),
- an average office be in operation for 3000 h/a,
- the light be in operation for about 2/3 of this time, yielding 2000 h/a,
- during half of this time, say, 1000 h/a,
- half of this power level be enough, i. e. 500 h/a savings potential, converted to full-load hours,
- the stand-by consumption, however, remaining active during all of the 8760 h/a.

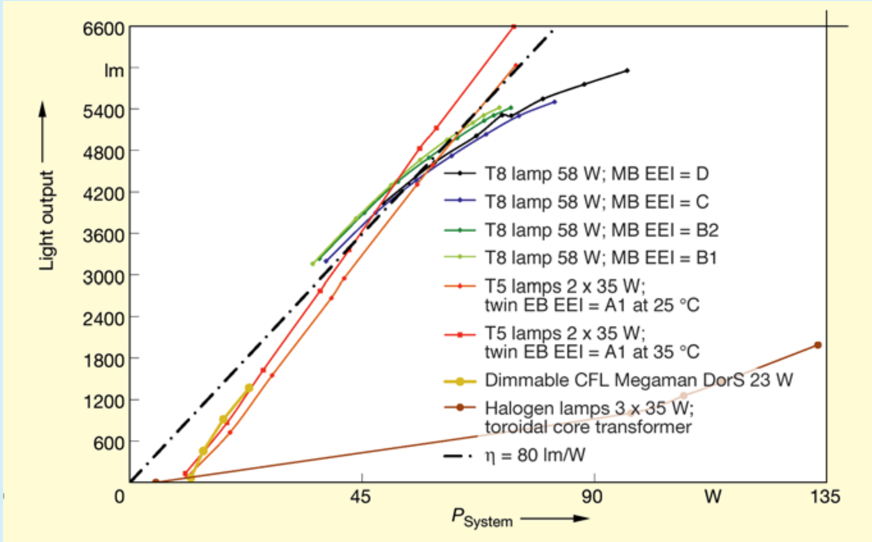
Yield the following calculation for the energy saved:

$$W = 500\,\frac{h}{a} * 55.8\ W = 28\,\frac{kWh}{a}$$

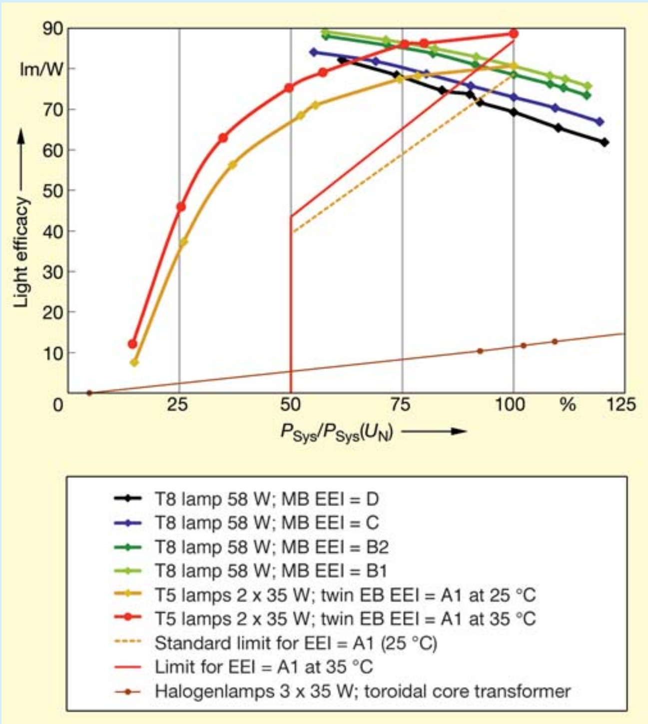
The basically useless additional consumption calculates as:

$$W_0 = 8760\,\frac{h}{a} * 3.2\ W = 28\,\frac{kWh}{a}$$

Thereby a savings potential does no longer exist. In some favourable exceptions this is taken into regard and installed accordingly [13], so that the user does not deplete the daily savings at night, but it remains to be doubted that this practical approach is the rule among specifiers and designers. On top of this, the above calculation does not even take the drop of efficiency due to dimming into account but instead assumes the efficiency of a dimmed system were equal to that of same system at full power, which is not the case.
Further, if installed as a refurbishment, each sensor and each actuator of such a monitoring system will need its own power supply from the mains. The net DC requirement may be as low as some very few milliwatts each, but each single one of them employs a mains adaptor including a small transformer. However, the smallest commercially feasible transformer is a unit rated around 1 VA and has about 1 W of no-load loss. Load loss may be negligible on account of a very low loading factor – but the multitude of such power supply units form the major constituent of the standby consumption in the entire lighting arrangement. Advanced control systems like EIB, which are easy and not too costly to install if the cabling has been prewired right during the construction phase of a building, employ one central AC adaptor for all connected units. Signals and the SELV DC supply share a common line. This technique provides the potential to cut the gross standby consumption down to a fraction. Excellent new technologies, components for which are offered by a great number of companies under the brand name Enocean [12] even provide the opportunity to power sensors and actuators without causing any stand-by consumption at all. Therefore it remains to be considered in each individual case whether the use of high-efficiency magnetic ballasts plus some less sophisticated control technique, simply shutting off parts or all of the lamps completely while not needed, could be both the cheaper and the more effective approach.



❶ **Light outputs of different systems employing T5 and T8 fluorescent lamps, plotted against the absolute electrical systems power input**



❷ **Light efficacies of different systems employing T5 and T8 fluorescent lamps, plotted against the relative electrical systems power input**

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