

Ballast Design Software

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Abstract: We have developed a Windows based application to assist engineers in the design of dimming or non-dimming electronic ballasts for Fluorescent lamps based around the I.R. range of lighting control ICs. The software reduces the design time dramatically by performing the complex iterative procedure required to optimize the operating points and component values of the circuit. It produces a schematic, a bill of materials (listing all component values) and winding specifications for the inductors. The software contains a database of operating parameters for 36 different types of lamp with the ability to add new lamps if required. It also supports 7 different configurations for one or two lamp ballast configurations.

I. INTRODUCTION

The ballast design software (to be referred to as BD in this paper) is *unique* in the way that it simplifies the design process to 5 simple steps requiring the user to specify only:

1. Line Input Voltage (US 80V-140V or Europe 185V-265V power factor corrected or non-power factor corrected)
2. Lamp Type (database of 36 lamps with the ability for the user to add additional lamp types)
3. Control I.C. (Version 2 supports the IR2156, the IR21571 and the IR2159, Version 3 will also support the IR2166 and IR2167)
4. The output configuration (one or two lamps, dual lamp series or parallel arrangement voltage or current mode cathode heating)

Having done this the user only has to press the **Design Ballast** button and the software will produce a complete design that will work correctly. The design process involves some lengthy and complex calculations that need to take into account many different operating parameters. Since it is an iterative process these calculations must be carried out several times in order to converge and provide acceptable operating points. Our software carries out this task almost instantaneously saving the ballast designer many hours of tedious calculation and possible error.

We have also included an inductor designer that will generate the specifications for the resonant output inductor as well as the power factor correction inductor if used. This process is also iterative and complicated. The software takes into account the very high inductor current that occurs during lamp ignition. This avoids the possibility of ballasts shutting down at lamp ignition due to saturation of the output inductor. It produces detailed specifications that contain all the information that a winding company would need in order to manufacture correctly designed parts that will work in the ballast without problems.



Figure 1, The Input Display

II. DESIGN PROCEDURE

The following parameters need to be known in order to calculate the operating parameters for a ballast non-dimming design:

(The values given here are for a T8/36W lamp)

- Preheat Current: 0.6 [A]
- Preheat Time: 2 [sec]
- Max Preheat Voltage: 600 [Vpp]
- Ignition Voltage: 1500 [Vpp]
- Running Lamp Power: 34 [W]
- Running Lamp Voltage: 141 [Vpk]

This information is contained within the lamp database within the software.

In a dimmable design these additional parameters are also needed:

- Lamp Power @ 2%: 1 [W]
- Lamp Voltage @ 2%: 215 [Vpk]
- Min. Cathode Heating Current: 0.35 [A]

(The minimum power is required whatever minimum light output is required)

The BD software uses a simplified model to design the output stage.

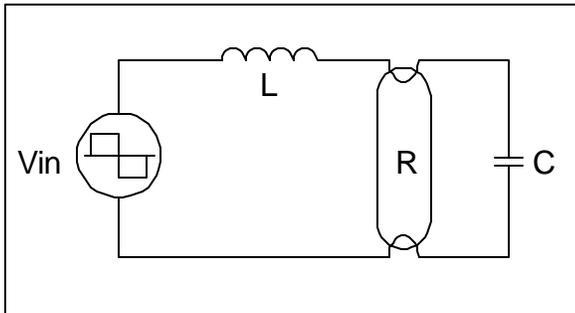


Figure 2, Output stage simplified model

A high performance ballast should provide the lamp with preheat current in the cathodes for a specified time to bring them to the correct temperature before ignition. During the preheat time the lamp voltage has to be low enough to ensure that ignition will not occur prematurely. At the end of preheat a high voltage is required to ignite the lamp and from then on the required current should be supplied to the lamp for operation at the correct power. These requirements are satisfied by changing the frequency of the input voltage and properly selecting; V_{in} , L and C . For preheat and ignition, the lamp is not conducting and the circuit is reduced to a series L-C. During running, the lamp is conducting and the circuit is an L in series with a parallel R-C. The BD uses the transfer functions for each mode of operation in an iterative process to determine the optimum values for L and C and to calculate the operating frequencies. It is essential to choose the best possible L and C values to optimize the design of the ballast.

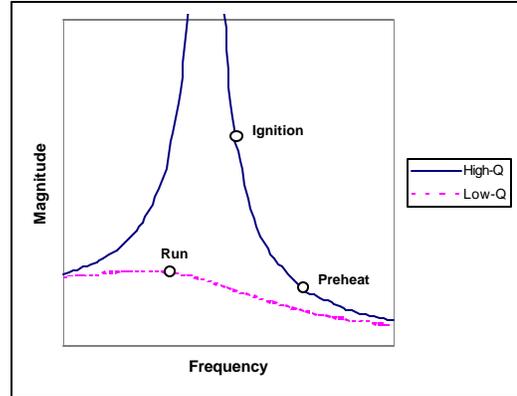


Figure 3, Transfer function of RCL circuit with typical operating points.

From this basic model we have extrapolated formulae to calculate the preheat frequency and voltage:

$$f_{ph} = \frac{I_{ph}}{2pCV_{ph}} \text{ [Hz]} \quad (1)$$

$$V_{ph} = -\frac{2V_{in}}{p} + \sqrt{\left(\frac{2V_{in}}{p}\right)^2 + \frac{L}{C}I_{ph}^2} \quad (2)$$

where,

- V_{in} = Input square-wave peak to peak voltage [Volts]
- V_{ph} = Lamp preheat peak-to-peak voltage [Volts]
- I_{ph} = Filament preheat RMS current [Amps]
- L = Output stage inductor [Henries]
- C = Output stage capacitor [Farads]

These equations take account only of the fundamental frequency of the square wave produced by the half bridge switches. Harmonics that exist at higher frequencies are assumed to have a negligible effect. Experimental results have confirmed that this assumption does not produce inaccurate results. The above formulae are used to determine the preheat requirements in a ballast that used *current mode* preheating which is the simplest approach. Some lamps require additional windings from the inductor or an additional transformer to provide the cathode heating because it is not possible to provide the correct current using values of L and C that are suitable for the running requirements of the lamp. The BD software uses a different method of approximation if such a configuration is selected. A configuration that relies on auxiliary windings from the inductor to

provide the preheat is termed *voltage mode*. This term does not imply that such a method would provide a constant voltage at the cathodes.

During ignition the frequency for a given ignition voltage is calculated using (3), since the lamp is still an open circuit.

$$f_{ign} = \frac{1}{2p} \sqrt{\frac{1 + \frac{4V_{in}}{V_{ign}}}{LC}} \quad \text{[Hz]} \quad (3)$$

where,

$$V_{ign} = \text{Lamp ignition peak to peak voltage [Volts]}$$

The associated ignition current amplitude flowing in the circuit that determines the maximum current ratings for the inductor L and the half bridge MOSFETs, becomes:

$$I_{ign} = f_{ign} C V_{ign} 2p \quad (4)$$

The software uses this current to design an inductor that will not saturate during ignition. This is important since otherwise the ballast would shut down at ignition.

Once the lamp has ignited the R in the model must be included in the equation so the following formula is used for calculating the running frequency:

$$f_{run} = \frac{1}{2p} \sqrt{\frac{1}{LC} - \frac{1}{2R^2C^2} + \sqrt{\left[\frac{1}{LC} - \frac{1}{2R^2C^2}\right]^2 - \frac{1 - \left(\frac{4V_{in}}{V_{run}p}\right)^2}{L^2C^2}}} \quad \text{[Hz]} \quad (5)$$

where R has been assumed to be the linearized lamp resistance determined from the lamp running power and voltage at a single operating point:

$$R = \frac{V_{run}^2}{2P_{run}} \quad \text{[Ohms]} \quad (6)$$

where,

$$\begin{aligned} P_{run} &= \text{Lamp running power [Watts]} \\ V_{run} &= \text{Lamp peak running voltage [Volts]} \end{aligned}$$

When calculating the design parameters for a dimming ballast the BD software also utilizes the equation used to determine the running frequency at maximum output, to determine the operating frequency at minimum output. The lamp database contains the measured lamp voltage and power for each lamp type at 2% light output.

$$\text{[Hz]} \quad (7)$$

An additional equation is used to calculate the cathode heating current at minimum output,

$$f_{\%} = \frac{1}{2p} \sqrt{\frac{1}{LC} - \frac{32P_{\%}^2}{C^2V_{\%}^4} + \sqrt{\left[\frac{1}{LC} - \frac{32P_{\%}^2}{C^2V_{\%}^4}\right]^2 - \frac{1 - \left(\frac{4V_{in}}{V_{\%}p}\right)^2}{L^2C^2}}} \quad (8)$$

Using the above series of equations, the software is carry out calculations very rapidly and determine

$$I_{Cath2\%} = \frac{V_{2\%} f_{2\%} p C}{\sqrt{2}}$$

whether an acceptable result is obtained. If not it will iterate the values of L and C until correct results are achieved.

Naturally the values of resistors and capacitors used for programming the frequencies and other operating parameters for the ballast control IC are calculated directly using the formulae that have been published in the data sheets for each part. These are directly calculated from the frequencies that the software has determined are correct for the L and C selected and the operating parameters of the system.

III. Simple Operation

When the BD software in simple mode, the user will never see any parameters or calculated results. At the end only a schematic with a bill of materials and specifications for the output inductor and power factor correction inductor are produced. This allows users to obtain the information needed to construct a ballast without being involved in or needing to understand the complex process of design.

IV. Advanced Operation

The BD software also has advanced options that allow the designer to adjust the parameters or fix the values

of the output inductor and capacitor. Having done this the software will then recalculate the operating points and component values required based around these values. The user will see a graphical display showing the preheat, ignition and running frequencies (for dimming designs the maximum and minimum frequencies are given) of the system and they will be able to see if these are acceptable. The calculated parameters can also be displayed and the user is able to adjust them and then recalculate should they wish to experiment with possible values of L and C other than those provided by the software. It is also possible to adjust the other operating parameters to find out what the effect would be if something were to be altered.

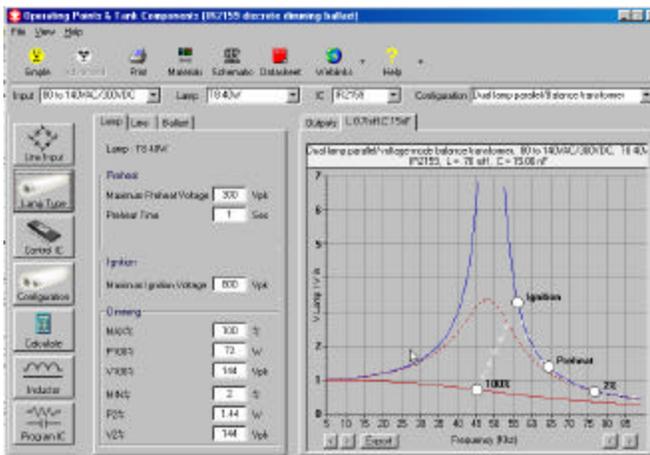


Figure 4, Advanced Display

V. Power Factor Correction

The BD software will also calculate the value of the inductor used in a design that employs an active power factor correction front end based on a critical conduction mode boost regulator. The current version of the software (V2) supports only the IR2156, IR21571 and IR2159, which do not have built in power factor control. They specify an industry standard controller in the bill of materials and show this in the schematic. The new ICs the IR2166 and IR2167 are equivalent to the IR2156 and IR21571 plus built in power factor control utilizing a simplified control method that negates the requirement for using an additional control IC. (These new ICs will be fully supported in Version 3 of the BD software, currently under development.)

In either case, since critical conduction mode is used, the equation to determine the inductance required and the peak current will be exactly the same.

$$L_{PFC} = \frac{V_{AC}^2 \cdot (V_O - \sqrt{2} \cdot V_{AC})}{2f_{MIN} \cdot P_O \cdot V_O} \quad (9)$$

$$I_{Lpk(MAX)} = 2\sqrt{2} \cdot \frac{P_O}{V_{AC}} \quad (10)$$

Where,

V_{AC} = RMS AC line voltage input

V_O = Output DC bus voltage

f_{MIN} = Minimum PFC switching frequency

P_O = Output Power

VI. Inductor Designer

The BD software also includes a complete inductor design feature that produces specifications for the ballast output inductor and PFC inductor (if applicable). The specification provides all of the following information from which an inductor can be manufactured that, if wound correctly, will be very close in value to the required value and will be acceptable for building into the ballast prototype circuit:

- Core Size
- Gap Length
- Winding wire diameter
- Number of turns

The software contains a database of core parameters for standard E cores made of standard power grade Ferrite material. The facility has also been included for the user to add additional core specifications to the database allowing any core to be designed into the system. The core data is stored in a Microsoft Access database. It should be noted that the core database should contain core information in ascending order of core size in order for the software to function correctly. This is because the design process begins with the smallest size and calculates until it reaches a size where the required inductance and peak current can be realized without the core saturating, i.e. exceeding a specified limit of flux density. The limit of 300mT has been chosen because this is very conservative and should provide enough headroom so that when the core temperature is high the inductor will never saturate under worst-case conditions of peak current.

The software also calculates the required wire diameter for the lamp running current and then works out whether the number of turns can be supported on the bobbin size available that will provide the correct inductance for the gap specified. The process begins with a small gap and calculates the number of turns then the peak flux density during ignition or worst-case peak current for a PFC inductor. If the flux density is too high a larger gap will be tried until a size of gap is found that will produce acceptable results. If no acceptable combination can be found the next size up of core will be tried, starting with a small gap and the process will take place again until the best solution is found. In this way the software saves the designer a considerable amount of time because this process actually carries out the calculations for many combinations until the optimum one is discovered.

The software produces an inductor specification that can be printed out and sent directly to a coil winder. As in advanced mode of the ballast design part of the software, the inductor will allow the core size or gap size or both to be fixed. If the core size is fixed then the software will calculate the gap size that will produce the best result and display the peak flux density, giving a warning if it is above 300mT. The same will happen if the gap size is fixed, the minimum size of core that may be used with this gap will be output.

In the case of both core and gap being fixed the software will simply calculate the number of turns and the peak flux density under worst-case conditions of peak current.

The number of turns required for an inductor with a specific core size and gap is give by:

$$N = \sqrt{\frac{L}{A_L}} \quad (11)$$

The Al value can be calculated from:

$$A_L = \frac{m_b \cdot m_g \times 10^{-6}}{\sum (l/A)} \text{ (nH)} \quad (12)$$

Where m_g varies depending on the size of the gap and be calculated from:

$$m_g = \frac{m_l}{1 + \left(\frac{G \cdot m_l}{l_e} \right)} \quad (13)$$

The peak flux density is given by:

$$B_{MAX} = \frac{N \cdot A_L \cdot I_{MAX}}{A_e} \quad (14)$$

Summary

The lighting group at I.R. has developed a unique and extremely useful design tool aimed at assisting our customers and reducing the development time required. It has been fully tested and has produced excellent results with ballast circuits that function without many of the common problems experienced by designers. It saves time and tedious repetitive work on the part of engineers and reduces the possibility of

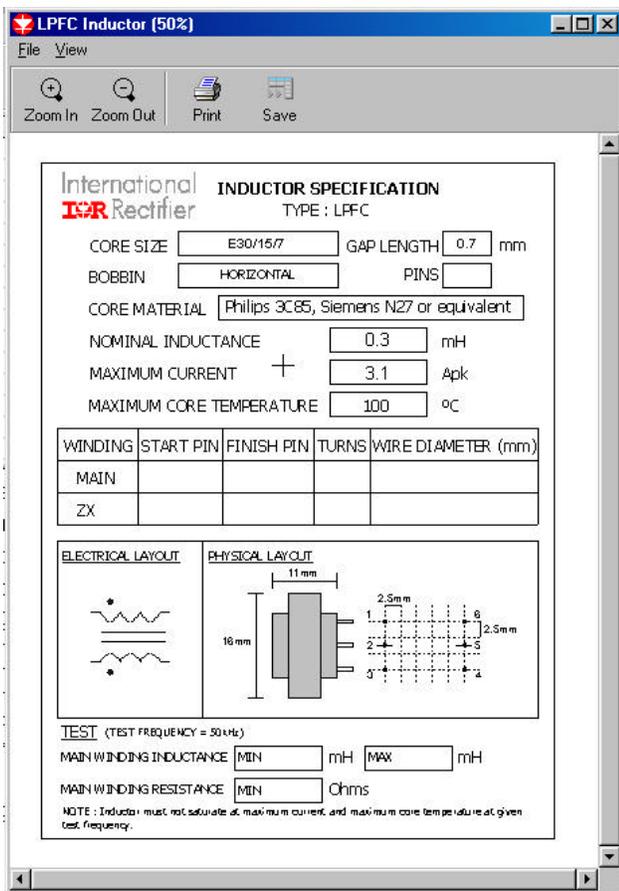


Figure 5, Inductor specification

error allowing the customer to cut down on development time of their first prototype allowing them to get something working on the bench more quickly. This software can be downloaded from the International Rectifier website at www.irf.com. It is easy install and use on a P.C. Version 3, which incorporates additional control ICs and features is currently under development.

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