EE 5741
Design of Electronic Ballasts

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Agenda

• Gas-Discharge lamps
• ZVS Resonant Half-Bridge output stage
• Typical ballast designs
• PFC
• Protection features
• Summary
Gas Discharge Lamp Basics

“Low Pressure” Fluorescent Lamp

- Current flows through plasma between electrodes
  - Must be AC or mercury migrates to one end
- Plasma emits mostly UV radiation
- UV excites coating to fluoresce and produce visible light
- Heated electrodes improve lamp life and lower strike voltage
Medium Pressure Lamp

- AC current flows through plasma between electrodes
- Plasma emits UV radiation AND visible light directly
## Why Gas Discharge Lamps?

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>• Lower total cost of ownership</td>
<td>• Higher initial cost</td>
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<tr>
<td>• Higher efficacy (Lumens/watt)</td>
<td>• Requires ballast for operation</td>
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<tr>
<td>• Broad-spectrum, high CRI (HID)</td>
<td>• Narrow spectrum, lower CRI (most fluorescent)</td>
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<td>• Long lifetime (15k hours)</td>
<td>• Long warmup time (HID)</td>
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<tr>
<td>• Dimmable (fluorescent)</td>
<td>• Disposal/recycling issues</td>
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Fluorescent Lamp Operating Modes

\[ V_{\text{lamp}} \]

- \( I = I_{\text{PH}}, V = V_{\text{PH}} \)
- \( V = V_{\text{IGN}} \)
- \( V = V_{\text{RUN}} \)

Start \(\rightarrow\) PH \(\rightarrow\) IGN \(\rightarrow\) RUN
Simple Ballast Block Diagram

Line Input → EMI Filter → Rectifier → DC Bus → Output Stage → Lamp

- UVLO
- Control Circuit
- Half-Bridge Driver
- Lamp Fault
Power stage - resonant LC Circuit
Parallel Resonant, Above Resonance
Design Constraints

- $f_{RUN} \geq 42KHz$ (infrared)
- $f_{PH} - f_{IGN} \geq 10KHz$ (tolerances)
- $V_{PH} \leq V_{PH_{MAX}}$ (ignition during preheat)
- $I_{IGN} \leq I_{MAX}$ (component ratings)
Typical Design Procedure for Ballast

Begin with lamp requirements

Lamp Type: 36W/T8

- 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]
Select Resonant L and C

1. Define Lamp Requirements
2. Select L and C Starting Values
3. Calculate Operating Points
4. Iterate L and C
5. Constraints Fulfilled?
   - No: Iterate L and C
   - Yes: Design Ballast
L and C selection example for linear lamp:
Lamp Type = T8/36W, $P_{\text{RUN}} = 32\text{W}$, $V_{\text{RUN}} = 141\ \text{Vpk}$, $V_{\text{PHMAX}} = 300\ \text{Vpk}$, $I_{\text{PH}} = 0.6\ \text{Arms}$, and $V_{\text{IGN}} = 600\ \text{Vpk}$.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Outputs</th>
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<tbody>
<tr>
<td>$L$ (H)</td>
<td>$C$ (F)</td>
</tr>
<tr>
<td>0.002</td>
<td>3.3E -9</td>
</tr>
<tr>
<td>0.002</td>
<td>6.8E -9</td>
</tr>
<tr>
<td>0.002</td>
<td>1.0E -8</td>
</tr>
<tr>
<td>0.002</td>
<td>1.5E -8</td>
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Adding Power Factor Correction
CrCM boost-mode PFC commonly used

Constant on-time control

Critical-conduction Mode (CrCM)
Advanced protection – lamp out circuit

SD pin (upper) and half-bridge voltage (lower) during lamp out/re-insert condition
The SD pin is internally biased at 2V. During end of life the lamp voltage will increase asymmetrically (DC end of life). The voltage offset sensed at the top of REOL4 will increase and one of the Zeners will turn on, therefore triggering the shutdown.

Vspec = VpK in the spec of the lamp
Example Ballasts
Summary

- Gas-discharge (Fluorescent) lamps offer:
  - Improved efficacy (lumens/watt)
  - Lower total operating cost
  - Better CRI lowers light output
- Ballast is necessary to operate lamp
- Ballast operates ZVS to minimize switching loss
- Ballast controls frequency to adjust lamp current
- Ballast self protects by shutdown when lamp misbehaves