# AN10713

## 18 W CFL lamp design using UBA2024 application development tool and application examples

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**Document information**

| Info | Content |
|---|---|
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| **Abstract** | Application note for the NXP UBA2024 and UBA2024A CFL driver |

### Revision history

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| 01 | 20090722 | first issue |

## Contact information

For more information, please visit: **http://www.nxp.com**

For sales office addresses, please send an email to: **salesaddresses@nxp.com**

# 1. Introduction

**WARNING**

**Lethal voltage and fire ignition hazard**

The non-insulated high voltages that are present when operating this product, constitute a risk of electric shock, personal injury, death and/or ignition of fire.

This product is intended for evaluation purposes only. It shall be operated in a designated test area by personnel qualified according to local requirements and labor laws to work with non-insulated mains voltages and high-voltage circuits. This product shall never be operated unattended.

The UBA2024 is an integrated half-bridge power IC, designed for use in an integrated/sealed Compact Fluorescent Lamps (CFL) at lamp output powers up to 22 W. Typical input voltages are from 100 V (AC) to 127 V (AC) and from 220 V (AC) to 240 V (AC). This application note describes typical integrated CFL applications in the 3 W to 18 W range, depending on lamp and input voltage. The term lamp is used when the burner and electronic ballast are meant.

The UBA2024 includes half-bridge power transistors with a level-shifter and drivers, bootstrap circuitry, an internal power supply, a precision oscillator and a start-up frequency sweep function for soft start and/or quasi-preheating. There are two versions of the UBA2024, the UBA2024, specified for (total) lamp powers of up to 15 W and the UBA2024A is intended for lamp powers that are above 15 W. The maximum lamp power depends on the lamp design and the dissipation of the IC. In this application note a non-dimmable 18 W application is described.

The UBA2024/UBA2024A is available as a DIP8 package (extension letter P after type code) and an SO14 package (extension letter T after type code). This document mainly describes the DIP package, but the same can be applied to the UBA2024 in SO14 package.

Due to the high level of integration, only a few external components are needed in a lamp ballast with the UBA2024.

## 1.1 Features

- Integrated half-bridge power IC for CFL applications (both power and controller)
- Accurate oscillator with adjustable frequency
- Soft-start by frequency sweep down from start frequency
- Quasi-preheat option (programmable sweep down timing)

## 1.2 System benefits

- Allows very compact integrated lamp ballasts which fit a small shell
- Low cost CFL applications due to low component count
- Higher reliability due to low component count
- Longer lamp life due to quasi-preheat
- Easy to apply
- Based on EZ-HV Silicon On Insulator (SOI) technology

- Can withstand a maximum voltage of 550 V

## 2. Circuit diagram

Figure 1 shows the typical circuit diagram of the UBA2024. Figure 2 shows a version with a voltage doubler for use in 120 V (AC) applications. The voltage doubler is needed for medium and high powers in regions that have lower mains voltages.

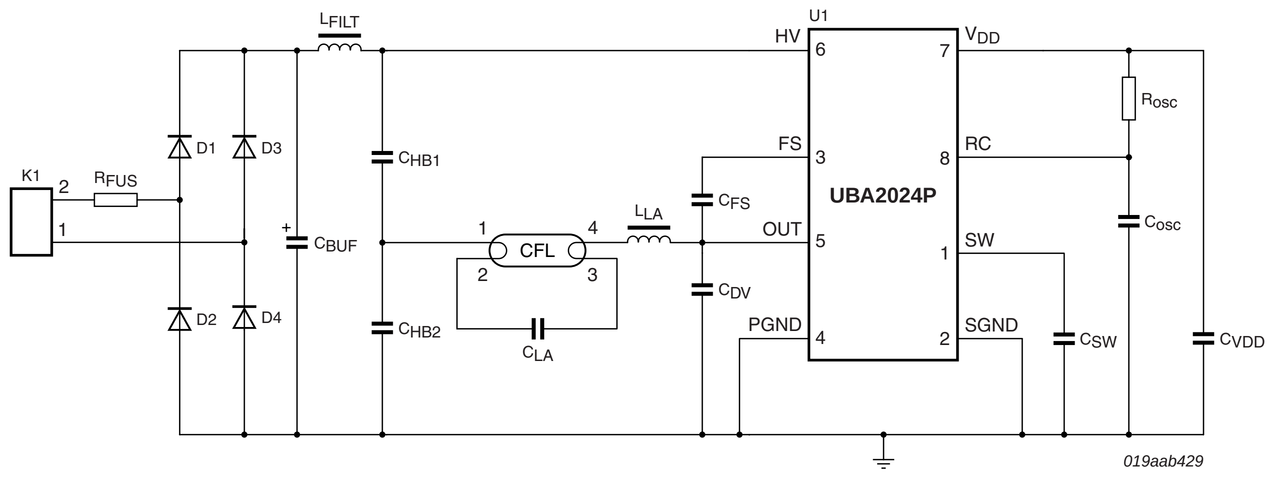



**Fig 1. Typical application diagram**

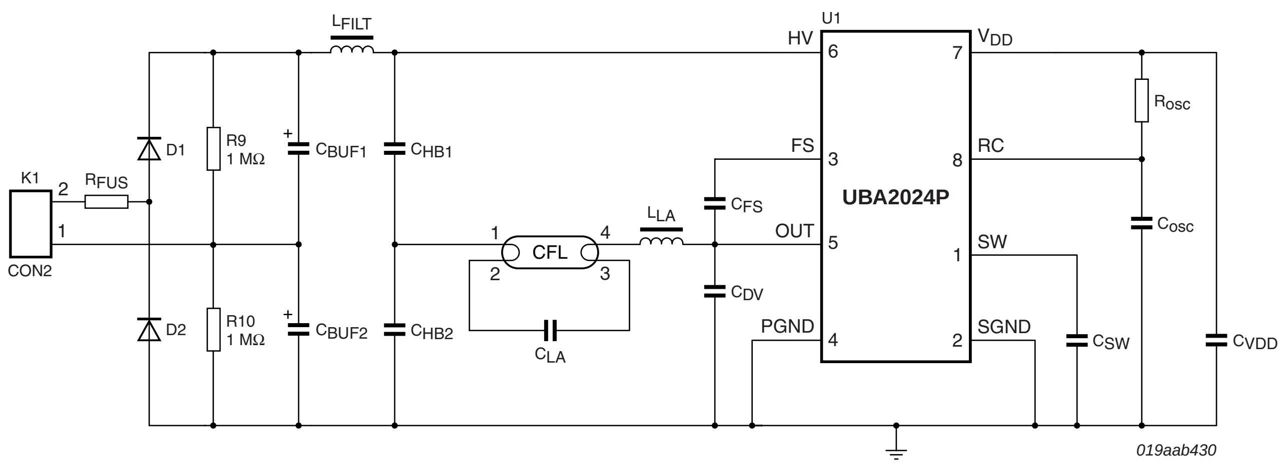



**Fig 2. Typical application diagram with voltage doubler**

See the *UBA2024 data sheet* for a functional description.

# 3. Design of an 18 W non-dimmable CFL

An application development tool is available to simplify the lamp design and calculation of the resonance circuit. This section explains the selection criteria for the component values. It also clarifies how to feed the application development tool with the appropriate values for components. With the tool and with the help of some practical guidelines it should be easy to set-up designs for different lamp powers. Throughout this document the light source itself is called the burner.

## 3.1 Selecting input configuration, buffer capacitor and fused resistor

Table 1 shows the values for the input section of the standard 230 V (AC) version and the 120 V (AC) version with and without a voltage doubler.

**Table 1. Advised input configuration**

| Input voltage | Driver IC | Lamp power[1] | Input configuration | $C_{BUF1}$ | $C_{BUF1}$, $C_{BUF2}$ | fused resistor[2] |
|---|---|---|---|---|---|---|
| 100 V (AC) to 127 V (AC) | UBA2024P UBA2024T | 4 W | Standard | 10 μF/200 V | n.a. | 18 Ω/(0.25 W/23 W) |
| | | 5 W to 6 W | | 15 μF/200 V | n.a. | 12 Ω/(0.5 W/35 W) |
| | | 7 W to 8 W | Voltage doubler | n.a. | 10 μF/200 V | 10 Ω/(0.5 W/47 W) |
| | | 9 W to 11 W | | n.a. | 15 μF/200 V | 8.2 Ω/(0.75 W/70 W) |
| | | 12 W to 14 W | | n.a. | 22 μF/200 V | 6.8 Ω/(1 W/103 W) |
| | UBA2024AP UBA2024AT | 15 W to 18 W | | n.a. | 22 μF/200 V | 6.8 Ω/(1 W/103 W) |
| 220 V (AC) to 240 V (AC) | UBA2024P UBA2024T | 5 W | Standard | 2.2 μF/400 V | n.a. | 47 Ω/(0.25 W/23 W) |
| | | 6 W to 8 W | | 3.3 μF/400 V | n.a. | 39 Ω/(0.25 W/23 W) |
| | | 9 W to 11 W | | 4.7 μF/400 V | n.a. | 33 Ω/(0.5 W/32 W) |
| | | 12 W to 15 W | | 6.8 μF/400 V | n.a. | 27 Ω/(0.5 W/47 W) |
| | UBA2024AP UBA2024AT | 15 W to 18 W | | 6.8 μF/400 V | n.a. | 15 Ω/(1 W/103 W) |

[1] Overall lamp power including driver circuit

[2] Minimum continuous power rating/minimum peak power rating (20 ms).

## 3.2 Choosing frequency, lamp inductor and capacitor

### 3.2.1 Input values

The application development tool calculates the component values based on the following input parameters:

- Selection of the driver IC type (UBA2024A type for lamp power > 15 W)
- Burner power
- Burner ignition voltage
- Burner operating voltage
- Mains input voltage and frequency (typical operating voltage)
- Combined value of the DC blocking capacitors

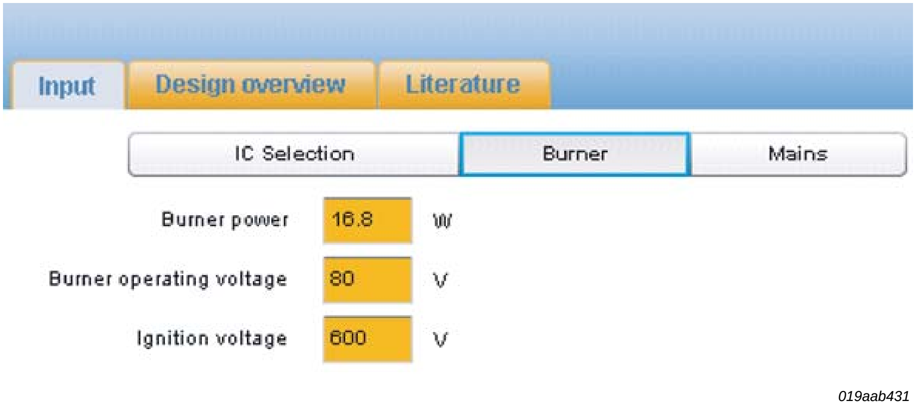
Figure 3 shows the part of the application development tool where the base values can be entered. The example shows the design of an 18 W lamp. This is the total lamp power which means 16.8 W burner power and approximately a 1.5 W loss in the electronic ballast. The burner used in this example is a replaceable burner. It is based on a G24q-2 fitting with the following parameters.

- Burner power = 16.8 W
- Burner voltage = 80 V
- Ignition voltage = 600 V

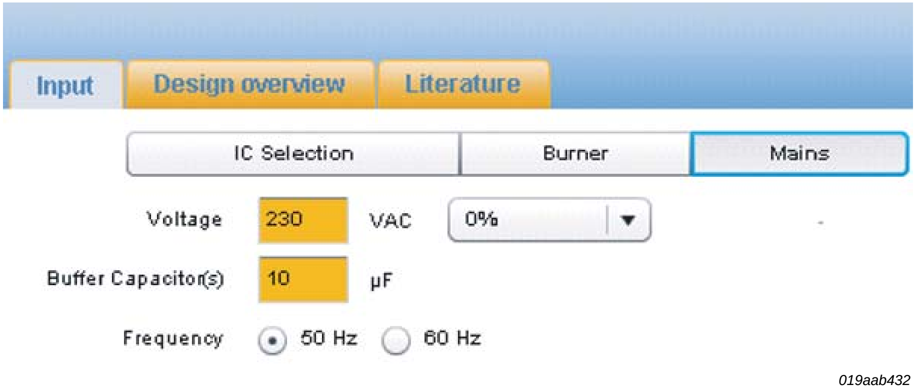
The following actions need to be taken:

1. Enter the burner parameters
2. Select the mains voltage to be used for the 18 W lamp (230 V (AC))
3. Select the IC (in this case the UBA2024AP, 8-pin DIL version)

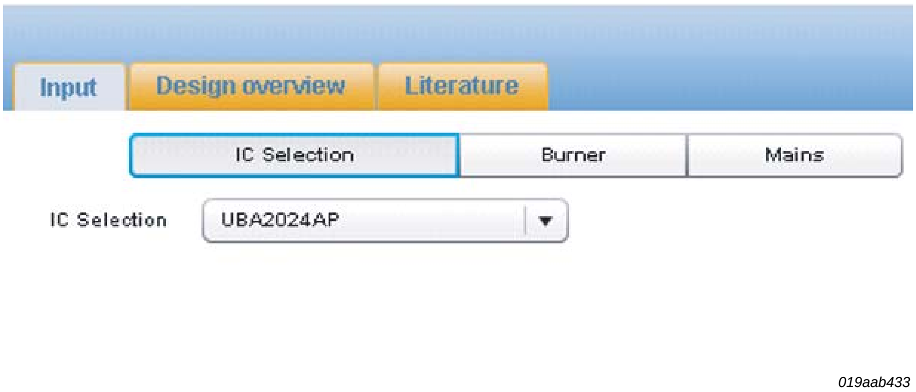
The UBA2024P cannot be used because the $R_{DSon}$ of its switches is too high.




a. Burner parameters




b. Mains voltage selection




c. IC selection

**Fig 3. Entering the design parameters for an 18 W lamp**

Using the lamp power given in Figure 3, the minimum value of the parallel DC blocking capacitors, CHB1 and CHB2 as a combined value, is advised in Figure 4. Using 16.8 W burner power, the advised minimum value is 2 × 68 nF, but 2 × 100 nF was chosen instead.

Based on the burner parameters mains voltage and frequency, the buffer capacitor listed in Table 1, and selected DC blocking capacitors, a first calculation of the LC resonance tank can be executed by pressing the Calculate button. The application development tool then calculates advisory values for the resonance inductor and capacitor. The default oscillator frequency is set to 42 kHz. After the Calculate button has been pressed for the first time, the actual values in Figure 4 have to be matched with the values in the advised fields on the right.

This is done in the left column (Actual) by entering values for the resonance capacitor and inductor shown in Figure 4. In this design the frequency is adjusted a little higher (45 kHz) to obtain an inductance of 2.1 mH and a capacitance value of 2.2 nF.

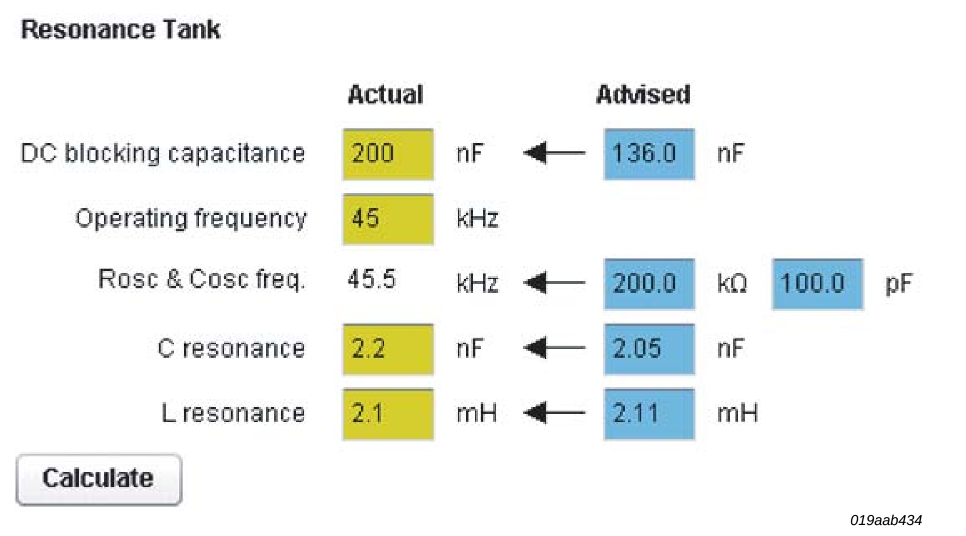



**Fig 4. Calculated advised values of the resonance circuit (blue fields, right) and actual entered values and operating frequency (green fields, left)**

When choosing the values for the L resonance ($L_{LA}$) and C resonance ($C_{LA}$) it is recommended to match the overall lamp power of the entered L and C resonance values with the calculated lamp power of the recommended resonance values. See Figure 5 (middle column).

Round off the C resonance to the nearest higher value available in the E range and later check in the lamp prototype if the chosen L and C resonances give a clean lamp turn-on as shown in Figure 12. If in the prototype the lamp turns on before ignition (the lamp current is flowing before ignition of the lamp and the voltage has dropped to a lower level), increase the value of C resonance to lower the ignition frequency ($f_{ign}$) and the lamp voltage during the quasi-preheat period. Ideally, $f_{ign}$ should be close to 1.7 times the operating frequency, $f_{out}$ (see Section 3.4). Alternatively, a larger $C_{SW}$ capacitor providing a longer quasi-preheat time can be a solution.

L resonance is, in most cases, a custom design and not a standard component allowing its value to be made to match closely with the advised value. Since the L mainly determines the lamp current and therefore the lamp power, it is best practice to round off L resonance to a higher value rather than to a lower value than advised. This can compensate for a higher line voltage tolerance on the oscillator frequency to preserve lamp life. The effect of line voltage tolerance can be added in the calculation by selecting a different percentage behind the mains voltage in Figure 3.

Figure 5 shows the range of power in the lamp for the specified conditions. The values **do not** indicate the minimum and maximum rectified AC mains voltage but the minimum and maximum voltages measured with an oscilloscope on pin $V_{HV}$ under load conditions (see Figure 12, channel 2). The values in Figure 5 are based on the entered values shown in Figure 3 and Figure 4.

**Summary**

| | Min | Avg | Max | |
|---|---|---|---|---|
| Bridge voltage (DC) | 280.4 | 302.1 | 323.9 | V |
| Power with advised L & C | 15.8 | 17.3 | 18.7 | W |
| Power in burner with entered L & C | 16.0 | 17.5 | 18.9 | W |
| **Burner current (1st harmonic)** | 200.2 | 218.6 | 236.9 | mA |
| **Coil current (1st harmonic)** | 206.3 | 224.2 | 242.0 | mA |
| Phase Shift | -53.0 | -55.9 | -58.4 | ° |

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**Fig 5. Average values (middle column) to set-up the design**

## 3.2.2 Calculation plots

Figure 6, Figure 7 and Figure 8 are based on the values entered in Figure 3 and Figure 4. Figure 6 shows the most important graph. This graph shows the lamp power based on the advised calculation (blue) and the lamp power based on the actual values (green) as function of the DC bridge voltage. If the values for $L_{LA}$ and $C_{LA}$ are correct the two lines should coincide.

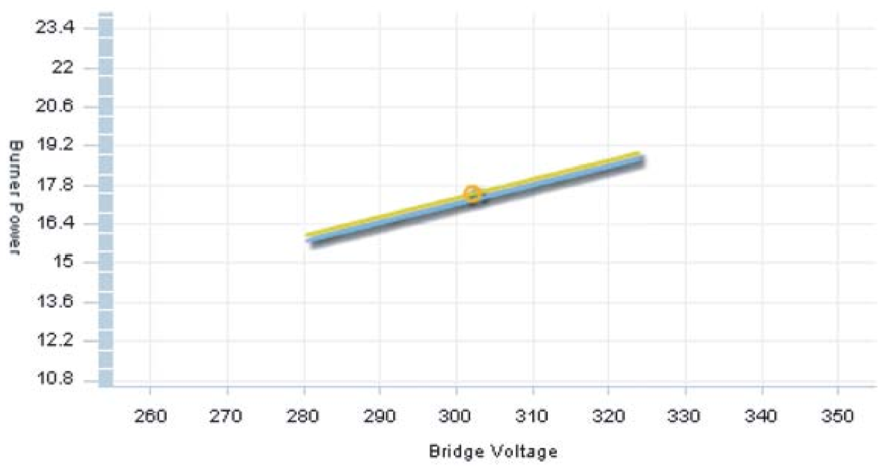


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**Fig 6. Lamp power versus bridge voltage**

Figure 7 shows the voltage to current phase shift between the voltage on and the current through the OUT pin of the IC caused by the L and C resonances, $C_{DV}$ and the lamp.

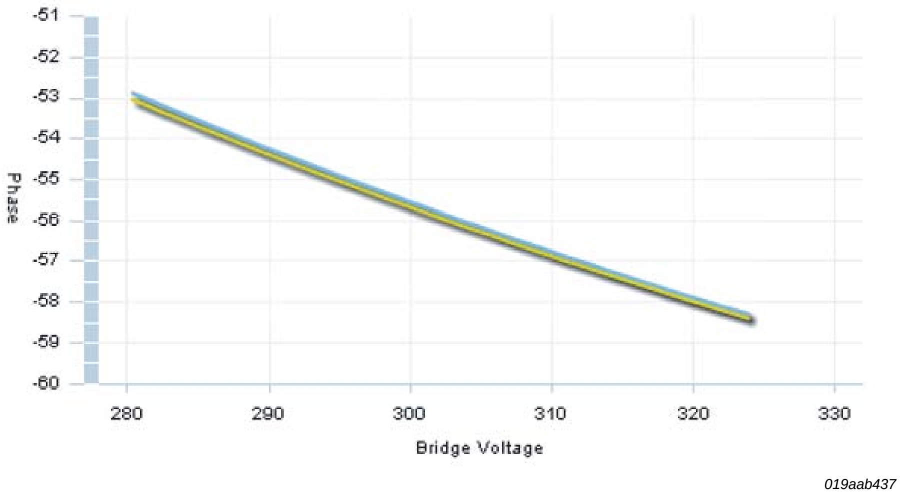


**Fig 7. V-I phase shift versus half-bridge voltage**

To guarantee safe operation, care must be taken that the phase shift between the output voltage and the output current is large enough to avoid capacitive mode. To be safe a phase shift lower than –20° is advised.

The preferred safe operating range is a phase shift between –40° and –60°. Lower phase shifts, lower than –60°, will cause extra losses in the power FETs as the reactive current does add to the losses in the UBA2024.

Figure 8 shows the continuous current through the UBA2024 FETs during normal operation. The RMS current should not exceed 270 mA for the UBA2024A.

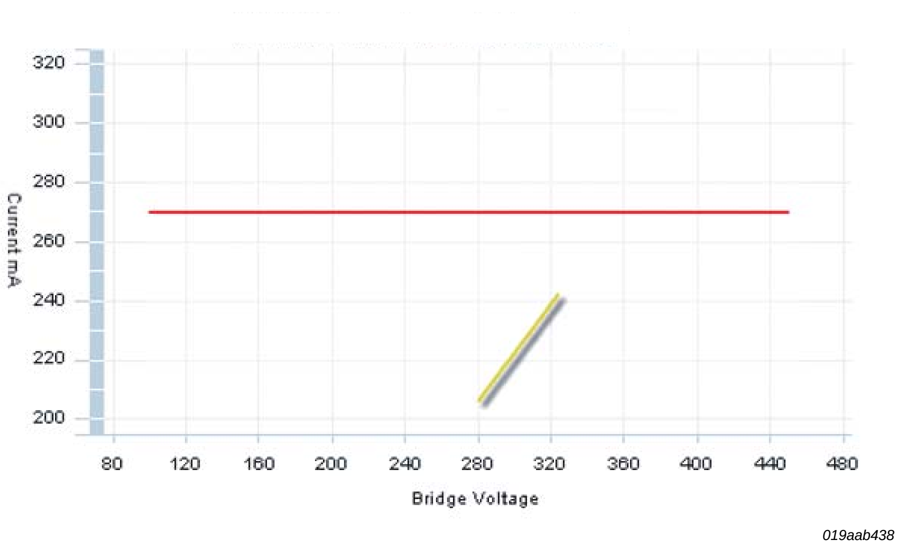


**Fig 8. FET currents as function of bridge voltage**

Figure 9 also shows the calculated ignition frequency. The ignition frequency depends on the burner and on the resonance circuit ($L_{LA}$, $C_{LA}$, DC-blocking capacitor and the voltage on $V_{bridge}$). The ideal ignition frequency for the UBA2024 is at 1.7 times the operating frequency.

Care must be taken that the ignition frequency is not lower than 1.6 times the operating frequency and not higher than 2.2 times the operating frequency. As the frequency sweep starts at 2.5 times the operating frequency, an ignition frequency that is too high will not give enough time for the quasi-preheat of the burner filaments. A warning is given in the application development tool if the resonance frequency is outside this range.

The application development tool has various built-in checks. It generates a warning or an error message in the status field when the chosen design values go beyond specification limits of the IC. The status information on the design becomes available when pressing the Status button.

When no suitable values for L or C resonances can be found, the operating frequency can be adjusted, so that a new set of values for L and C resonances can be calculated. Real values of available components should be entered in the “Application actual values” section. This can be repeated until a satisfactory solution has been found. See Section 3.3 for more information on the operating frequency.

### 3.2.3 Coil

In the section “Coil designs parameters” (example in Figure 9), the most important requirements for the inductor are shown. These together with the inductance entered in Figure 4 and the operating temperature of the inductor should be enough information to design a coil. Due to losses in the inductor, the operating temperature of the inductor is higher than the lamp ambient temperature. When the coil is properly designed, the inductor temperature rise will be around 40 °C above the ambient temperature. In case a warm lamp is switched off and on again, the inductor should not saturate at this inductor temperature.

**Coil (L resonance)**

| | | |
|---|---|---|
| Ignition peak current | 715.8 | mA |
| E Peak Ignition | 1075.9 | mJ |
| Ignition frequency | 86.3 | kHz |

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**Fig 9. Requirements for coil design**

### 3.2.4 Thermal properties

In this section the estimated dissipated power and the estimated junction temperature in the IC is calculated. See Figure 10 for an example. When the maximum ambient temperature at which the lamp needs to operate is entered, the expected junction temperature is calculated. The junction temperature must not exceed 150 °C. If the junction temperature does exceed the 150 °C the expected operating life time of the IC is reduced significantly.

The maximum stress allowed during the ignition phase is 900 mA (peak) on the UBA2024 and 1.35 A (peak) on the UBA2024A at a case temperature of 25 °C (repetition rate is less than once per hour). The maximum stress period must not be longer than 1 s.

**Thermal**

| | | |
|---|---|---|
| Ambient Temp | 70 | °C |
| Average powerloss in FET | 0.56 | W |
| Total power loss | 0.74 | W |
| Case temperature | 128.6 | °C |
| Junction temperature | **140.5** | °C |

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**Fig 10. Dissipated power and expected junction temperature in the IC**

### 3.2.5 Literature reference

The formulas behind the calculations in the Excel spreadsheet are based upon Ref. 1 and Ref. 2.

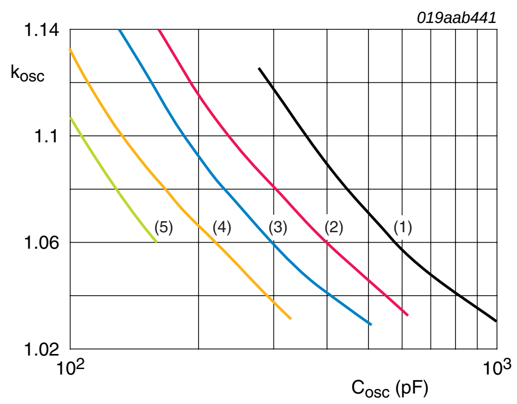
## 3.3 Operating frequency

An operating frequency, $f_{out}$, of up to 60 kHz (the maximum nominal output frequency for the UBA2024, corresponding with a start-up frequency of 150 kHz. See the *UBA2024 data sheet* for start-up sequence description) can be selected. However, an $f_{out}$ between 25 kHz and 30 kHz or between 40 kHz and 50 kHz is usually selected. This is because below 25 kHz there may be audible noise. Operation within the 30 kHz to 40 kHz band may result in interference with infrared remote controls. At higher than 50 kHz the third harmonic is in the range where conducted emission requirements for most countries have to be met. Since inductors and capacitors decrease in size and cost with increase in frequency, the 40 kHz to 50 kHz range is preferred.

$f_{out}$ is set by $R_{OSC}$ and $C_{OSC}$ according to Equation 1:

$$f_{out} = \frac{1}{k_{OSC} \times R_{OSC} \times C_{OSC}} \quad (1)$$

Practical values for $R_{OSC}$ range from 50 kΩ to 400 kΩ. Note that the lower the value of $R_{OSC}$, the higher the $V_{DD}$ output current is going to be, thus increasing the total package dissipation. Practical values for $C_{OSC}$ range from 100 pF to 1 nF. The advised value for $C_{OSC}$ is 180 pF for 40 kHz to 50 kHz and 270 pF for 25 kHz to 30 kHz. Figure 11 shows the oscillator constant $k_{OSC}$.




(1) $R_{osc}$ = 50 kΩ.

(2) $R_{osc}$ = 80 kΩ.

(3) $R_{osc}$ = 100 kΩ.

(4) $R_{osc}$ = 200 kΩ.

(5) $R_{osc}$ = 400 kΩ.

**Fig 11. Typical $k_{OSC}$ dependency of $R_{OSC}$ and $C_{OSC}$ for UBA2024**

## 3.4 Ignition frequency and quasi-preheating

The IC output starting frequency is about 2.5 times the nominal output frequency and gradually decreases, depending on lamp type and temperature, until the nominal output frequency is reached. The lamp inductor ($L_{LA}$) and the lamp capacitor ($C_{LA}$) boost the lamp voltage gradually higher as the output frequency gets closer to their resonance frequency, until it is sufficient to ignite the lamp. In the meantime, the current in the resonance circuit flows through the filaments providing quasi-preheating.

The UBA2024 circuitry stops the frequency sweep at the resonance frequency, $f_{rsn}$, if the lamp has not ignited yet (see the UBA2024 data sheet for details). This ensures a maximum effort to ignite the lamp. The resonance frequency depends on $L_{LA}$ and $C_{LA}$:

$$f_{rsn} = \frac{1}{2\pi\sqrt{L_{LA} \times C_{LA}}} \quad (2)$$

As the ignition frequency, $f_{ign}$, is higher than or equal to the resonance frequency the resonance frequency should be chosen so that the preferred ignition frequency is $1.6 \times f_{out} \leq f_{ign} \leq 1.8 \times f_{out}$.

The time needed to sweep down (set by $C_{SW}$) from the start frequency to the resonance frequency can be used as an approximation for the ignition time. The sweep time is typically $C_{SW}$ (nF) $\times$ 10.3 ms. The ignition time is shorter for large values because the lamp ignites before the resonance frequency is reached. The typical ignition time is 1 s when $C_{SW}$ = 330 nF. A larger $C_{SW}$ makes the sweep time longer and the preheating of the electrodes better. However, the rise of the preignition lamp ignition voltage is also slower. Both a quasi-preheat that is too short and a voltage rise that is too slow increase the glow time of the lamp. This reduces the lifetime of the lamp. During the glow phase, the lamp is ignited but the filaments and the gas inside the lamp are not at their final operating temperature.

The UBA2024 has a mechanism to push extra energy into the lamp during this glow phase. This makes the lamp go to its final light output quicker which gives a longer lifetime for the lamp. Typical values for $C_{SW}$ are between 33 nF and 330 nF.

## 3.5 Choosing the other components

A bridge cell or separate diodes like the 1N5062 can be used for the rectifier bridge. The 1N4007 can also be used but these diodes are more sensitive to voltage spikes.

With a lamp current $\geq$ 150 mA with $C_{DV}$ = 220 pF and for a current $\geq$ 150 mA with $C_{DV}$ = 100 pF the value of $C_{VDD}$ and $C_{FS}$ is 10 nF.

The recommended half-bridge capacitors ($C_{HB1}$ and $C_{HB2}$) are greater than 47 nF when $f_{out}$ = 40 kHz to 50 kHz and greater than 68 nF when $f_{out}$ = 25 kHz to 30 kHz.

The resonance frequency of the input pi filter, consisting of $L_{FILT}$ and $C_{HB}$ ($C_{HB}$ being the effective capacitor as seen on the HV pin of the IC, i.e. the series capacitance of $C_{HB1}$ and $C_{HB2}$), has to be at least two times lower than the nominal output frequency.

**Remark:** Performance and lifetime cannot be guaranteed by using the values given in this section. The lamp and the UBA2024 performance strongly interact with each other and need to be qualified together as a combination.

## 3.6 About component tolerances

Typical tolerances can be used (20 % for electrolytic capacitors, 10 % for other capacitors (foil or ceramic) and 5 % for resistors and inductors) for all components.

Since $R_{OSC}$, $C_{OSC}$ and $L_{LA}$ determine the lamp current, their tolerance also determines the spread in the lamp current. Therefore, the required lamp current accuracy may require closer tolerance for $R_{OSC}$, $C_{OSC}$ and $L_{LA}$.

- **Example 1:** If $R_{OSC}$ = ± 5 %, $C_{OSC}$ = ± 10 %, $L_{LA}$ = ± 5 %, $C_{LA}$ = ± 10 % and the internal frequency of the IC = ± 3 %, the effective lamp current tolerance is 12.6 %.
- **Example 2:** If $R_{OSC}$ = ± 1 %, $C_{OSC}$ = ± 5 %, $L_{LA}$ = ± 5 %, $C_{LA}$ = ± 5 % and the internal frequency of the IC = ± 3 %, the effective lamp current tolerance is 7.1 %.

# 4. Quick measurements

Table 2 compares the calculated values from the application development tool with measured values.

**Table 2. Measured values compared with the calculated values**

| Lamp power (W) | Power factor (pF) | Input voltage/ frequency (V/Hz) | Input configuration | $f_{out}$ set (kHz) | $f_{out}$ measured (kHz) | $L_{lamp}$ calculated (mA) | $L_{lamp}$ measured (mA) | P burner (W) | P burner measured (W) |
|---|---|---|---|---|---|---|---|---|---|
| 18.3 | 0.59 | 120/60 | doubler | 45.5 | 43.0 | 208 | 211 | 16.5 | 17.1 |
| 18.0 | 0.54 | 230/50 | standard | 45.5 | 45.6 | 218 | 204 | 16.5 | 16.6 |

# 5. Start-up and stop waveforms

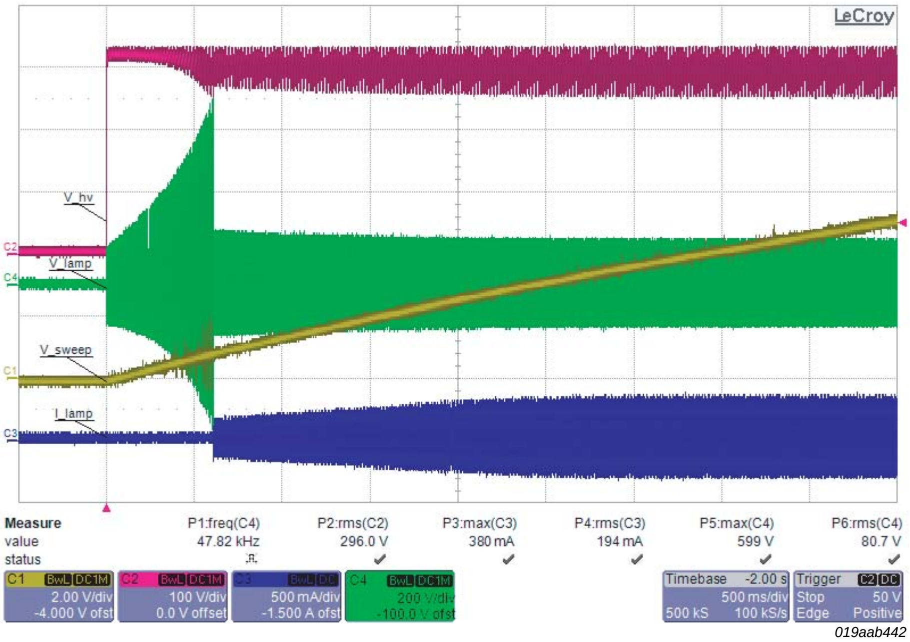



**Fig 12. Cold start lamp waveforms; the first 650 ms there is quasi-preheating of the filaments. $C_{SW}$ = 220 nF.**

# 6. Layout considerations

The UBA2024 PCB layout, has a considerable influence on the performance of the IC. Issues to be taken into account are:

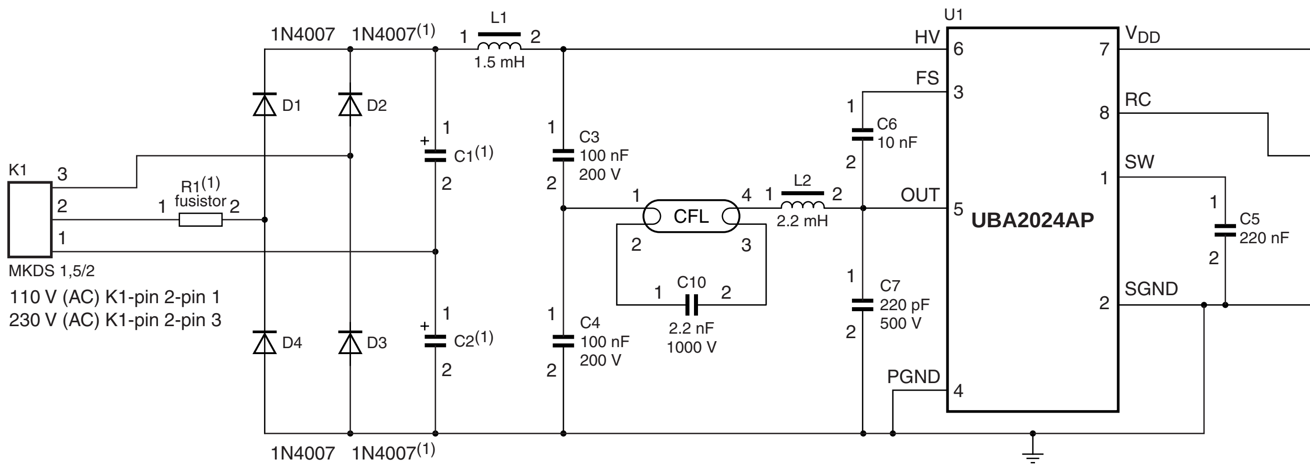
- Coils with open magnetic circuits should not be placed opposite the IC (on the other side of the PCB). If an axial filter inductor is used for $L_{FILT}$ it should be placed in the same direction as the IC to minimize magnetic field pick-up.
- The oscillator pin (pin 7, RC) and the sweep pin (pin 8, SW) should be shielded from output/lamp by a ground track.
- Components on pins 7 and 8 should be placed as close to the IC as possible.
- Capacitors $C_{VDD}$ and $C_{FS}$ should be placed close to the IC.
- Mains input wires must not run parallel or near the half-bridge signal (pin 5, OUT) or near the output of the lamp inductor, bypassing the input filter.
- If the UBA2024(A)T is used, all SGND pins need to be soldered to a copper plane for effective heat transfer. This copper plane is underneath the IC and extends as much as possible on both sides of the IC. Fixing the IC to the board using thermal conductive glue also helps cooling the IC.

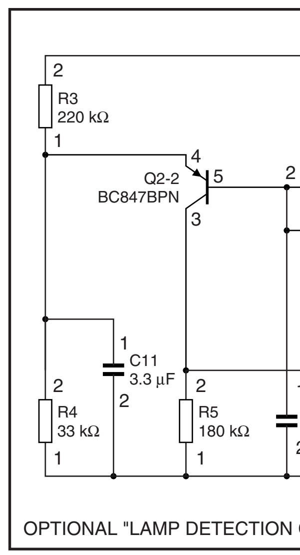
# 7. Application examples

## 7.1 Reference board

### 7.1.1 External lamp detection circuit

The NXP Semiconductors evaluation board has an additional lamp detection circuit which is not required in mass production applications like CFLi (see Figure 13). In this section the functioning of this detection circuit is described.




(1)NOTE! design combines 110V (AC) and 230V (AC)

120 V (AC):
R1 = 6.8 Ω/1 W
C1, C2 = 22 μF/200 V
D2 and D3 NOT mounted
K1 mounted on position 1, 2

230 V (AC):
R1 = 10 Ω/1 W
C1 = 10 μF/400 V
C2 = wire bridge
D1 to D4 are all mounted 1N4007
K1 mounted on position 2, 3

**Fig 13. Circuit diagram demo board with optional lamp detection circuit**

During start-up, in the quasi-preheat and the ignition phase, the voltage at the SW pin (pin 1) increases from 0 V to 3 V. At the same time, the amplitude of the signal on the RC pin (pin 7) increases by the same amount. However, if the lamp is not ignited because it is broken or missing, the sweep voltage stays below the 3 V level or even drop to 0 V. The IC will not operate in Zero Voltage Switching mode (ZVS). Large currents run through the half-bridge causing the dissipation in the IC to exceed the maximum value. The half-bridge can only withstand the high dissipation until the junction temperature reaches 150 °C.

At start-up, the RC oscillator starts with an amplitude of 2 V on pin RC (pin 7). The half-bridge frequency is now running at 2.5 times the nominal operating frequency. When the burner is connected to the circuit the half-bridge operates in ZVS and the $C_{SW}$ capacitor charges. R6, R7 and C12 create an average DC voltage of the oscillator voltage on pin RC which is basically half the amplitude. That voltage is then fed to the base of Q2-2 which functions as a comparator.

At the same time that $C_{SW}$ is charging, C11 is charged by R3 from $V_{DD}$. This takes place with a time constant of (R3/R4) $\times$ C11. Charging stops when the voltage on C11 reaches 1.6 V. The voltage on C11 is fed to the emitter of Q2-2 to compare it with its base voltage.

Under normal conditions during start-up, when the lamp is connected, the average DC voltage from RC rises above 1.6 V at the end of the charging period for C11. The base emitter voltage of Q2-2 stays reverse based and will not turn on. If, however, non-ZVS is detected in the switches of the half-bridge driver, because of an unconnected or broken lamp, charging of $C_{SW}$ stops and the voltage on $C_{SW}$ drops to 0 V. The average DC voltage on the RC pin lowers to less than 1 V and Q2-2 starts to conduct.

Q2-2 drives the latching transistor Q1-1 and the fault condition is latched by the left diode of the double diode, D5. At the same time the right diode of D5 stops the UBA2024 half-bridge oscillator. The latch can be reset by power cycling the mains voltage with less than 1 s delay (for the test circuit this depends on the discharge time of C11 and R4). The latch circuit is designed in such a way that it is not noise sensitive. However, it is better to keep it away from the large signal tracks.

Typically, the circuit triggers within 0.5 s from start-up when no lamp is connected. It also triggers when a lamp is removed while operating. When the protection is tripped, the dissipated power in the IC is approximately 0.6 W. The IC can dissipate this power continuously.

Ensure that there is some reaction time margin (at room temperature) when choosing C11. Also, consider voltage de-rating of MLCC capacitors when low voltage types are used. It is advisable to choose an X7R type or an X5R type of at least 10 V.

The protection circuit puts some additional capacitive loading (about 5 pF) on pin RC. This can become significant for small values of $C_{OSC}$. In this case the value of $C_{OSC}$ is compensated for this effect by lowering $R_{OSC}$ from 200 kΩ to 191 kΩ (E96 series), giving an operating frequency of 45.9 kHz instead of 43.3 kHz. When the circuit is used it is advisable to add the extra 5 pF to $C_{OSC}$ in Equation 1.

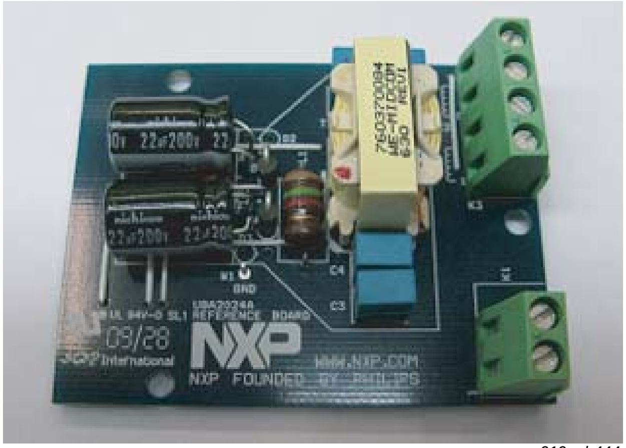



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Fig 14. Photo reference board UBA2024T/AT (120 V (AC) version)

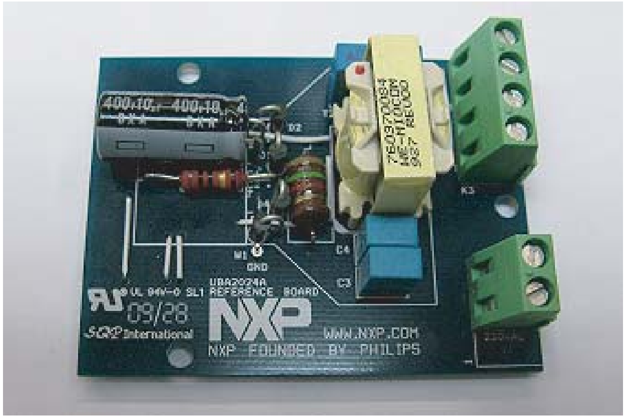


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Fig 15. Photo reference board UBA2024T/AT (230 V (AC) version)


019aab446

Fig 16. Photo reference board UBA2024P/AP (120 V (AC) version)


019aab447

Fig 17. Photo reference board UBA2024P/AP (230 V (AC) version)

**Table 3. Component values used for testing with 18 W PLC burner**

| Reference | Description | Remarks | Value/type 230 V (AC) | Value/type 120 V (AC) |
|---|---|---|---|---|
| $R_{FUS}$ | fusible inrush current limiter resistor | - | 10 Ω/1 W | 6.8 Ω/1 W |
| D1, D4 | mains rectifier diodes | - | 1N4007 | 1N4007 |
| D2, D3 | mains rectifier diodes | - | 1N4007 | not mounted |
| $C_{BUF1}$ | buffer capacitor | - | 10 μF/400 V | 22 μF/200 V |
| $C_{BUF2}$ | buffer capacitor | high temperature electrolytic type | not mounted, place wire | 22 μF/200 V |
| $L_{FILT}$ | filter inductor | axial type | 1.8 mH | 1.8 mH |
| $C_{HB1}$, $C_{HB2}$ | half-bridge capacitors | - | 100 nF/250 V (DC) | 100 nF/250 V (DC) |
| $C_{LA}$ | lamp capacitor | film type, capable of withstanding peak voltages of twice its DC-rating | 2.2 nF/700 V (DC) | 2.2 nF/700 V (DC) |
| $L_{LA}$ | lamp inductor | E20-core | 2.2 mH | 2.2 mH |
| $C_{DV}$ | dV/dt limiting capacitor | - | 220 pF/500 V (DC) | 220 pF/500 V (DC) |
| $C_{FS}$ | floating supply buffer capacitor | - | 10 nF/50 V | 10 nF/50 V |
| $C_{VDD}$ | low voltage supply buffer capacitor | - | 10 nF/50 V | 10 nF/50 V |
| $C_{OSC}$ | oscillator capacitor | 2 % | 100 pF/50 V | 100 pF/50 V |
| $R_{OSC}$ | oscillator resistor | 1 % | 191 kΩ/0.125 W | 191 kΩ/0.125 W |
| $C_{SW}$ | sweep time capacitor | - | 220 nF/25 V | 220 nF/25 V |

**Table 4. Components values for the optional lamp detection circuit**

| Reference | Description | Remarks | Value/type |
|---|---|---|---|
| R3 | - | - | 220 kΩ/0.125 W |
| R4 | - | - | 33 kΩ/0.125 W |
| R5 | - | - | 180 kΩ/0.125 W |
| R6, R7 | - | - | 1 MΩ/0.125 W |
| C11 | ignition time-out capacitor | MLCC X7R type or an X5R type with a voltage rating ≥ 10 V | 3.3 μF/10 V |
| C12 | - | ceramic or MLCC C0G type | 220 pF/16 V |
| D5 | double diode common cathode | - | BAV70W |
| Q1-1, Q2-2 | PNP/NPN transistor in one package or use separate transistors (see below). | $h_{FE}$ > 100 at 10 μA | BC847BNP |
| | Q1-1 | $h_{FE}$ > 100 at 10 μA | BC847B |
| | Q2-2 | $h_{FE}$ > 100 at 10 μA | BC857B |

## 7.2 UBA2024 with additional feed-forward circuit

### 7.2.1 Introduction

With a typical half-bridge topology, the output power and current depends on the bus voltage. When the mains voltage increases the dissipated power increases. This could cause lamp failure or the IC junction temperature to exceed the maximum allowed temperature (150 °C). This can be prevented by implementing a feed-forward circuit. With feed-forward, a higher bus voltage causes a higher operating frequency and a lower half-bridge current which in turn compensates for the bus voltage increase.

Typically, a feed-forward circuit is only needed if the mains voltage increases by up to 30 % for a long period of time (which only occurs in a few countries in the world). The application development tool calculation shows how much power is put in the lamp and what the resulting current will be. This limit differs from application to application.

### 7.2.2 Implementation

Feed-forward can easily be applied via the additional circuit R1, R2 and Q1 as shown in Figure 18. The system should be designed so that the feed-forward circuit does not inject current in $C_{OSC}$ at the typical operating point of the lamp. In a 230 V (AC) mains system, the circuit should not operate at a voltage below √2 × 230 V (AC) = 325 V. This circuit starts to inject current in the oscillator capacitor when $V_{HV}$ equals:

$$V_{HV} = (V_{VDD(min)} + 0.7)\left(1 + \frac{R1}{R2}\right) \quad (3)$$

In the example of Figure 18 this yields:

$$V_{HV} = (11.7 + 0.7)\left(1 + \frac{2.0M}{78.7k}\right) = 328V \quad (4)$$

Above 328 V the injected current into the oscillator pin equals:

$$\Delta I_{CF} = \frac{\Delta V_{bus}}{R1} = \frac{\Delta V_{bus}}{2.0M} \quad (5)$$

Results:

An 18 W CFL circuit has been applied with and without feed-forward as described above. The results can be seen in Figure 19.

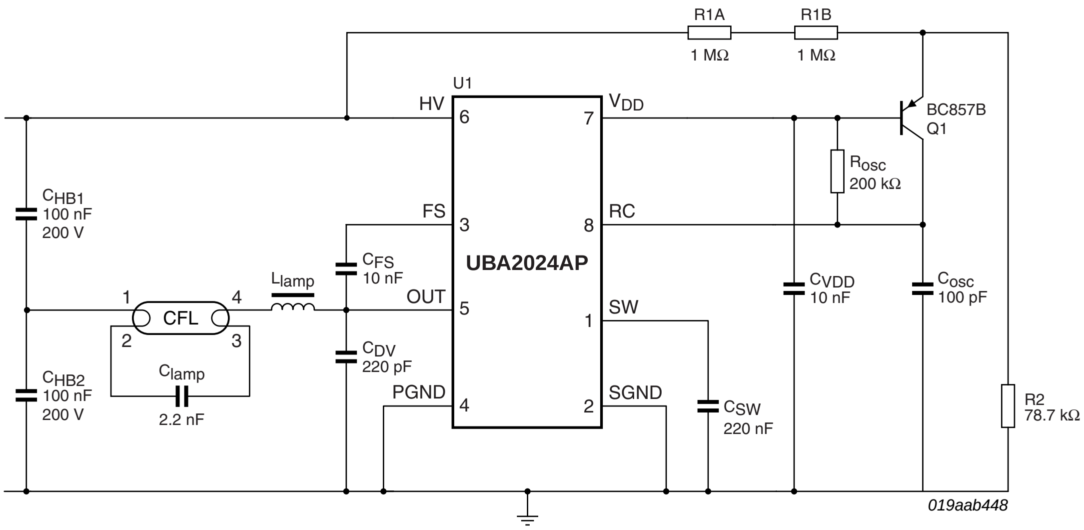
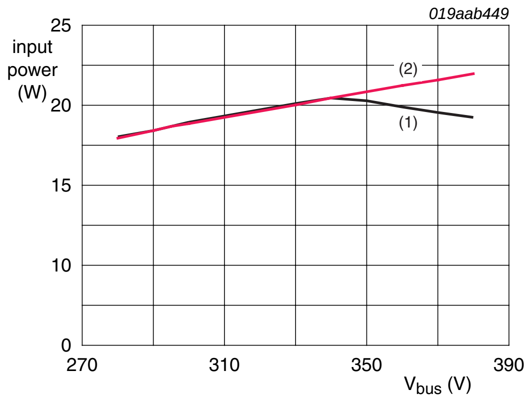



Fig 18. Example feed-forward circuit




(1) Pin feed-forward (W).

(2) Pin no feed-forward (W).

Fig 19. Feed-forward results

## 7.3 Driving a CCFL lamp with the UBA2024

Using a transformer instead of a coil, the UBA2024P can be used to drive Cold Cathode Fluorescent Lamps (CCFL). Figure 20 shows the circuit diagram for a CCFL application. Due to EMI, a high voltage (2 kV) capacitor of 2.2 nF may need to be connected to pin 1 of the primary winding (grounded side) and to pin 3 of the secondary winding.

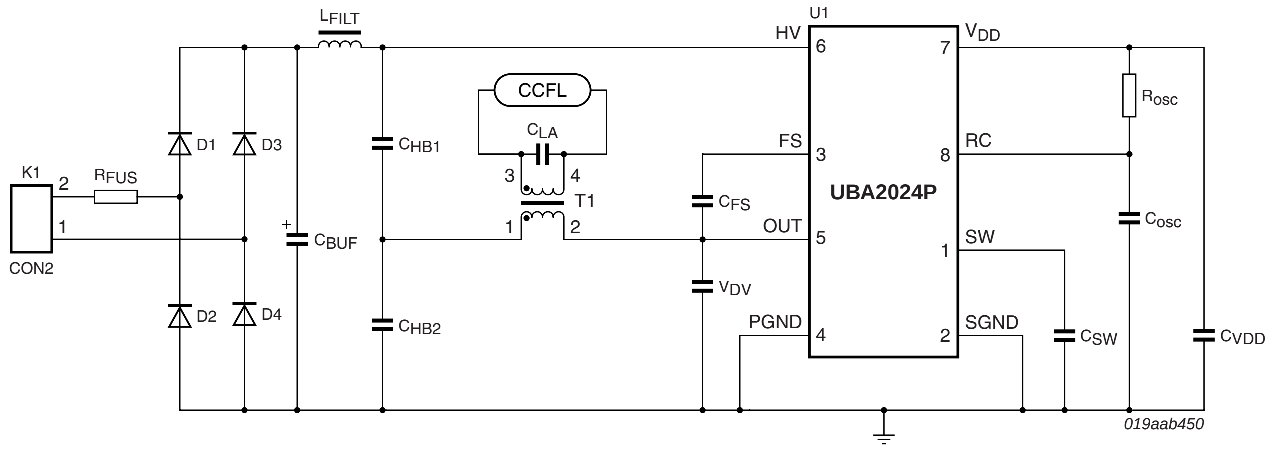



Fig 20. Circuit diagram of UBA2024 for CCFL

## 7.4 UBA2024 in a replaceable lamp configuration (matchbox ballast)

The UBA2024 in Figure 21 is not powered unless a lamp is in place. Therefore, when a lamp is replaced it automatically starts when the new lamp is inserted. This is particularly useful when the UBA2024 is used in so-called 'matchbox' ballasts driving 4-pin, PL-C, Dulux D/E Dulux T/E, DBX or TBX type of burners.

Since the IC is intended for use in low cost integrated CFL applications, it lacks an open or no-load protection circuit. Therefore, the protection circuit, as described in Section 7.1.1 and shown in Figure 13, is a requirement for this application. Using only three resistors and a single transistor. an optional feed-forward circuit can be added, limiting the lamp power if the mains voltage becomes too high. This extends the lamp lifetime. The UBA2024AP is a recommended component to drive the higher power burners of up to 18 W.

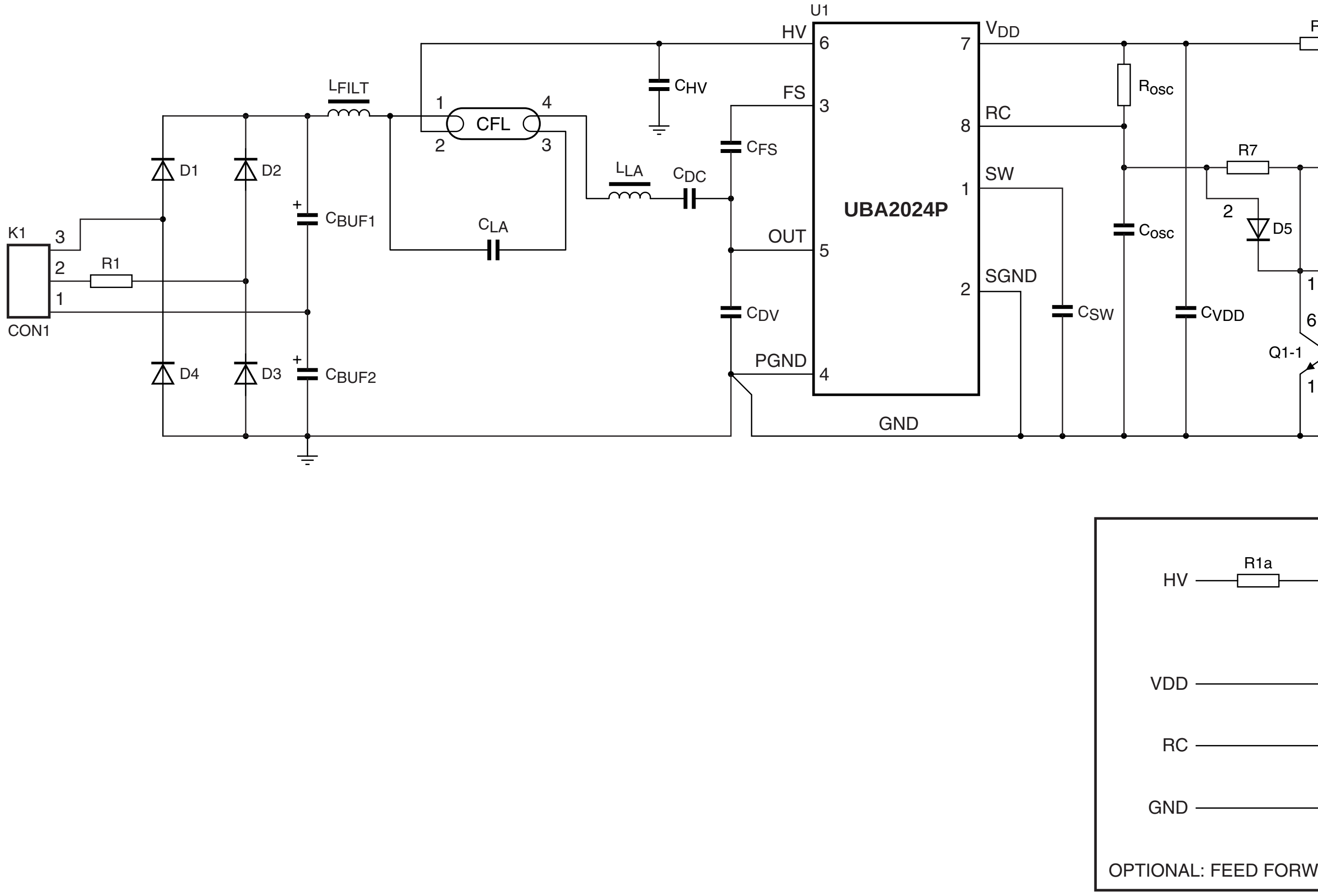



Fig 21. Circuit diagram for replaceable lamp with required protection and optional feed-forward

**Table 5. Component values used for replaceable 18 W burner (80 V /210 mA**

| Reference | Description | Remarks | Value/type 230 C (AC) | Value/type 120 V (AC) |
|---|---|---|---|---|
| $R_{FUS}$ | fusible inrush current limiter resistor | - | 10 Ω/1 W | 6.8 Ω/1 W |
| D1, D4 | mains rectifier diodes | - | 1N4007 | Not mounted |
| D2, D3 | mains rectifier diodes | - | 1N4007 | 1N4007 |
| $C_{BUF1}$ | buffer capacitor | - | 10 μF/400 V | 22 μF/200 V |
| $C_{BUF2}$ | buffer capacitor | high temperature electrolytic type | not mounted, place wire | 22 μF/200 V |
| $L_{FILT}$ | filter inductor | axial type | 1.8 mH | 1.8 mH |
| $C_{dc}$ | half-bridge capacitor | - | 150 nF/400 V (DC) | 150 nF/400 V (DC) |
| $C_{LA}$ | lamp capacitor | film type, capable of withstanding peak voltages of twice its DC-rating | 2.2 nF/700 V (DC) | 2.2 nF/700 V (DC) |
| $L_{LA}$ | lamp inductor | E20-core | 2.1 mH | 2.1 mH |
| $C_{DV}$ | dV/dt limiting capacitor | - | 220 pF/500 V (DC) | 220 pF/500 V (DC) |
| $C_{FS}$ | floating supply buffer capacitor | - | 10 nF/50 V | 10 nF/50 V |
| $C_{VDD}$ | low voltage supply buffer capacitor | - | 10 nF/50 V | 10 nF/50 V |
| $C_{OSC}$ | oscillator capacitor | 2 % | 100 pF/50 V | 100 pF/50 V |
| $R_{OSC}$ | oscillator resistor | 1 % | 191 kΩ/0.125 W | 191 kΩ/0.125 W |
| $C_{SW}$ | sweep time capacitor | - | 220 nF/25 V | 220 nF/25 V |

**Table 6. Components values for the lamp detection circuit and optional feed forward**

| Reference | Description | Remarks | Value/type |
|---|---|---|---|
| R1A, R1B | optional; feed forward | - | 1 MΩ/0.125 W |
| R2 | optional; feed forward | - | 78.7 kΩ/0.125 W |
| R3 | - | - | 220 kΩ/0.125 W |
| R4 | - | - | 33 kΩ/0.125 W |
| R5 | - | - | 180 kΩ/0.125 W |
| R6, R7 | - | - | 1 MΩ/0.125 W |
| C11 | ignition time-out capacitor | MLCC X7R type or X5R type | 3.3 μF/10 V |
| C12 | - | ceramic or MLCC C0G type | 220 pF/16 V |
| D5 | double diode common cathode | - | BAV70W |
| Q1-1, Q1-2 | PNP/NPN transistor in one package or use separate transistors (see below). | $h_{FE}$ > 100 at 10 mA | BC857B/BC847 or BC847BNP |
| | Q1-1 | $h_{FE}$ > 100 at 10 mA | BC847B |
| | Q2-2 | $h_{FE}$ > 100 at 10 mA | BC857B |
| Q2 | optional; feed forward | - | BC857B |

# 8. Improved preheat

In this section an improved preheat methodology is explained, in which the starting frequency is set and consequently the time needed to reach ignition frequency. The circuitry connected to pin SW has therefore changed compared to the application as shown in the data sheet of the UBA2024. The new preheat circuit is shown in Figure 22.

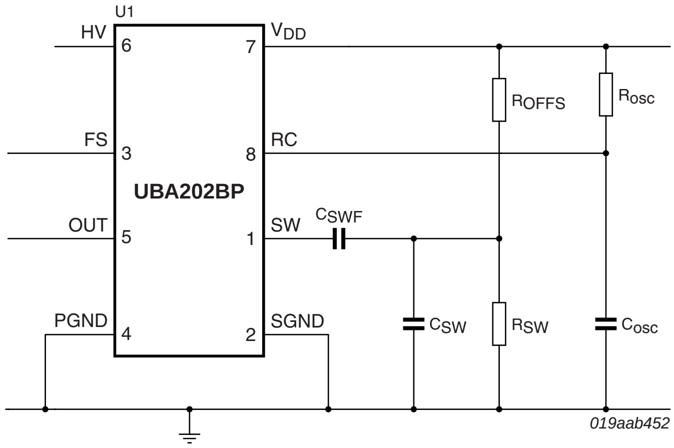



**Fig 22. New preheat circuit**

A controlled preheat current where the current would appear as shown in Figure 23 is not possible. There is no free pin available and a sense resistor would lead to additional power losses.

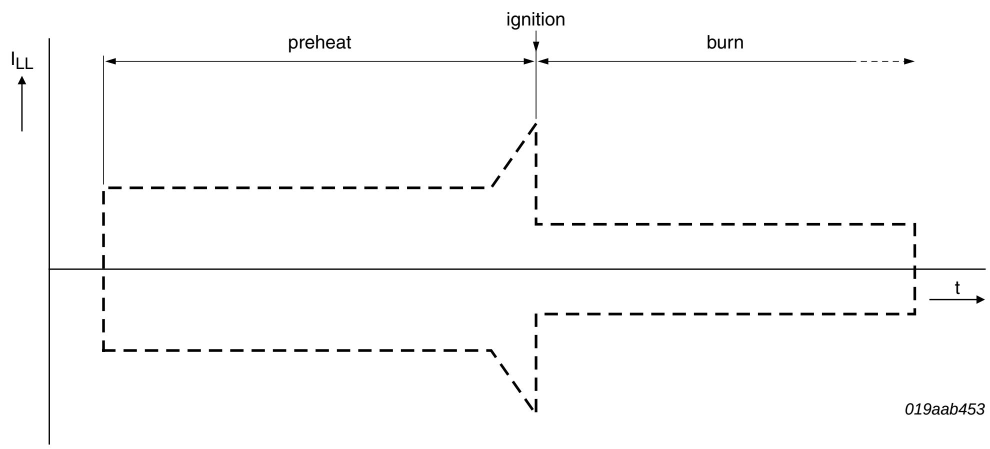



**Fig 23. Controlled preheat current**

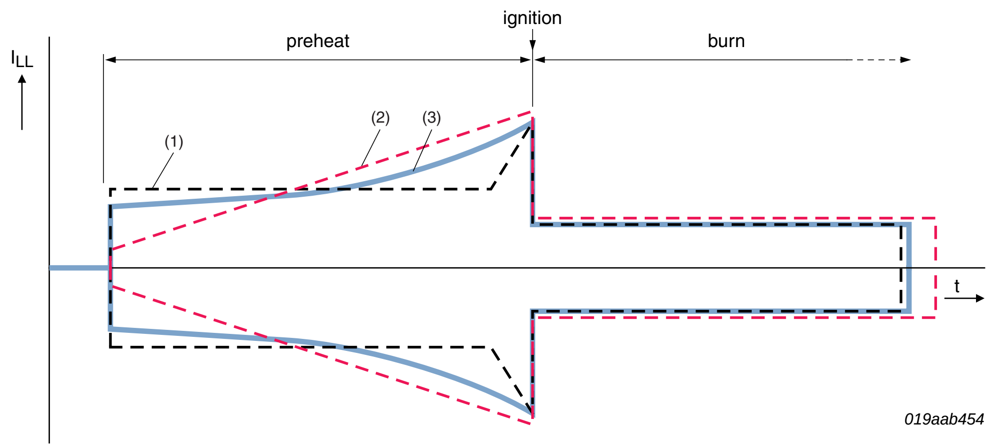
The following sections of this chapter describe how a controlled preheat can be approximated for the typical application shown in this application note (see Figure 1 and Figure 2). Proof of concept is shown in Section 9 that this approximation of a controlled preheat is an adequate solution for preventing lamp glow.

If the filament specifications are unknown, a guideline is that the optimal ratio between the filament resistance at ignition and cold filament resistance is approximately 5 : 1. Using a preheat time of 500 ms to 600 ms this ratio can be reached. With a cold start not only is the ignition voltage higher but also the starting voltage. Both ignition and starting cause more damage during a cold start.

## 8.1 Start-up of an application with the new preheat circuit

The time needed to sweep down (set by $C_{SW}$ only as $R_{SW}$ is not present when the IC is used in the typical application shown in the *UBA2024 data sheet*) from the start frequency to the resonance frequency can be used as an approximation for the ignition time.

The sweep time is typically $C_{SW}$ nF $\times$ 10.3 ms. The ignition time is shorter for large values because the lamp ignites before the resonance frequency is reached. The typical ignition time is 1 s when $C_{SW}$ = 330 nF. A larger $C_{SW}$ increases the sweep time and improves the preheating of the electrodes. However, the rise of the pre-ignition lamp ignition voltage is also slower. Both a quasi-preheat that is too short and a voltage rise that is too slow increase the glow time of the lamp. This reduces the lifetime of the lamp. During the glow phase the lamp is ignited but the filaments and the gas inside the lamp are not at their final operating temperature. The UBA2024 has a mechanism to push extra energy into the lamp during this glow phase which is described in the *UBA2024 data sheet*. This makes the lamp reach its final light output faster giving a longer lamp lifetime. Typical values for $C_{SW}$ are between 33 nF and 330 nF when the IC is used in a typical application.




(1) Controlled preheat.

(2) Quasi-preheating at 100 kHz.

(3) Preheat starting at $f_{ign}$ + 10 kHz.

**Fig 24. Preheat and ignition, preheat current as a function of time**

In Figure 22, a schematic diagram of the SW circuitry is shown which also provides a starting frequency of approximately 10 kHz above the ignition frequency.

In this operation, the operating frequency is still determined by $R_{OSC}$ and $C_{OSC}$ according to Equation 1. The starting frequency is determined by the offset voltage that is determined by the voltage divider $R_{OFFS}$ and $R_{SW}$.

Capacitor $C_{SW}$ now works as a filter for this offset voltage. After start up $C_{SWF}$ is charged further until the IC has reached the operating frequency. This preheating method is similar to curve (3) shown in Figure 24.

The component values used in a 230 V/18 W UBA2024AP application using the new preheat circuit are $C_{SWF}$ = 470 nF, $C_{SW}$ = 10 nF, $R_{SW}$ = 10 kΩ, $C_{OSC}$ = 220 pF, $R_{OSC}$ = 100 kΩ and $R_{OFFS}$ = 430 kΩ.

# 9. Lamp glow

Lamp glow is mainly caused by incorrect preheating of the filaments. Either a quasi-preheat that is too short or a voltage rise that is too slow increase the glow time of the lamp. This reduces the lifetime of the lamp. During the glow phase the lamp is ignited but the filaments and the gas inside the lamp are not at their final operating temperature.

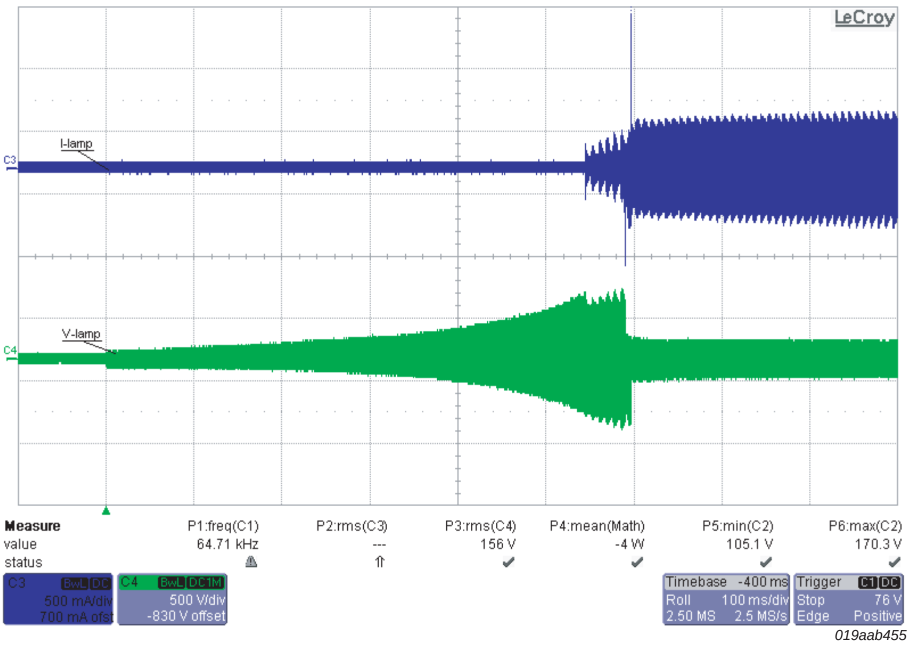



**Fig 25. Lamp glow caused by improper preheating**

In Figure 25, it is clear that there is still a high voltage present at the lamp while at the same time lamp current is flowing. When the filaments and gas inside the lamp have reached their normal operating temperature, the voltage at the lamp will drop to its normal operating value.

This is the preheating method shown in Figure 24 referred to as Quasi-preheat and starts at 100 kHz.

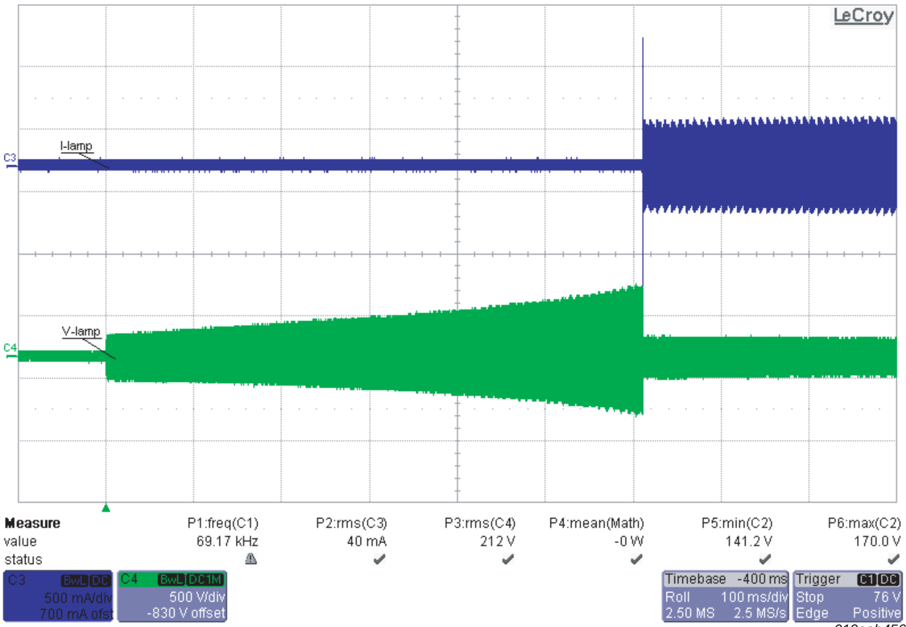



**Fig 26. Proper ignition of the lamp due to proper preheating, without glow**

Figure 26 shows the ignition of a lamp that is preheated as shown in Figure 24 according to the blue line, where preheating starts at the ignition frequency plus an additional 10 kHz. There is no lamp glow present due to the filaments having enough time to reach the correct operating temperature. This method of preheating increases lamp lifetime and ensures it passes any on/off test of 10,000 repetitions minimum.

# 10. Coil saturation

Figure 27 illustrates what happens when the coil goes into saturation during ignition.

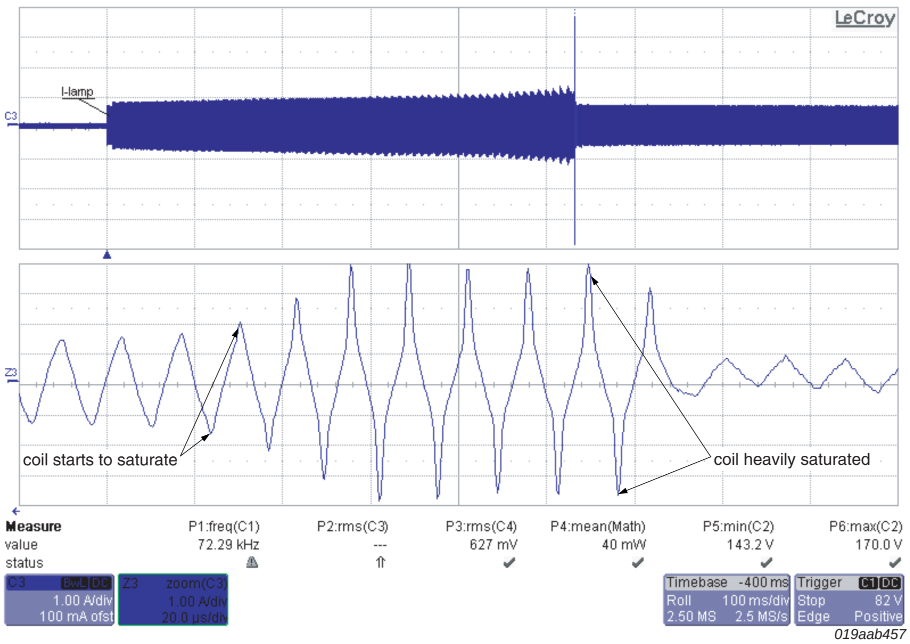



**Fig 27. The coil current during ignition when the coil is saturated**

In this case, the coil current shows excessive peaks which results in the integrated half-bridge switches going into saturation and consequently damaging the IC.

The test circuit shown in Figure 28 provides a simple method to determine the saturation current of an inductor.

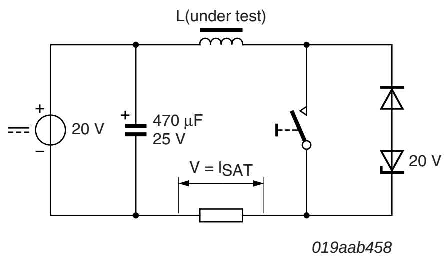



**Fig 28. Inductor saturation test circuit**

The electrolytic buffer capacitor is charged by the 20 V power supply and is discharged through the inductor when the push-button switch is pushed. The inductor current can be measured as the voltage over the 1 Ω resistor. The diode circuit clamps the voltage peak over the push-button switch when it is released. An example of the inductor current is shown in Figure 29.

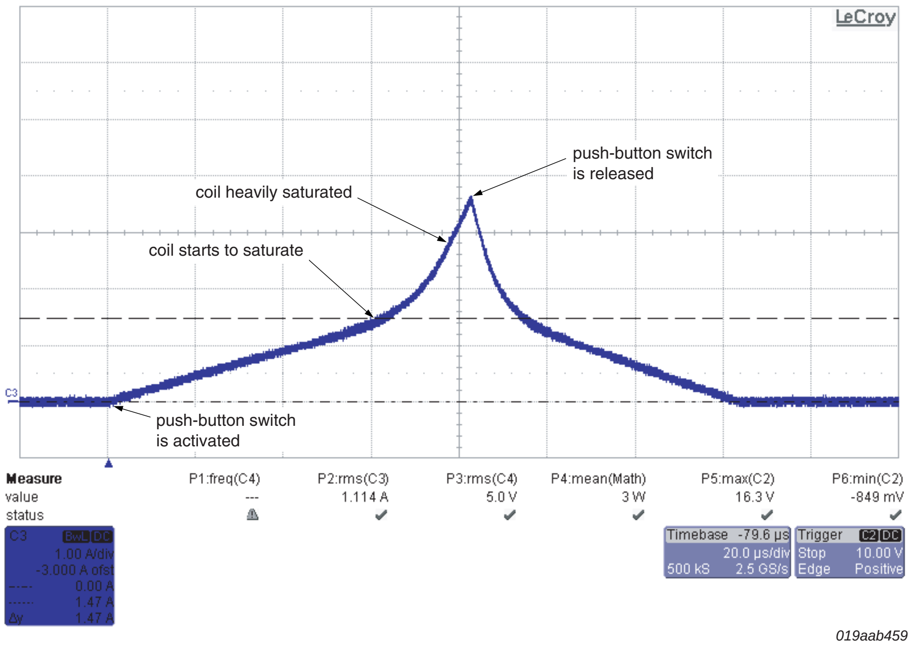



Fig 29. The current though an inductor going into saturation

As long as the inductor is not saturated, the current through the windings builds up linearly until the moment that the coil saturates. At that moment a rapid current increase can be observed, as indicated in Figure 29.

When an application is used under extreme conditions such as a combination of maximum possible mains voltage and high temperature a well designed inductor can still go into saturation during ignition. To correct for such boundary conditions, a protection circuit is presented to keep the application from breaking down when coil saturation occurs.

The best method to prevent coil saturation is to use a properly designed inductor with good coil material and that the presented method is no excuse to use a poor dimensioned inductor coil.

The basic principle is that when the coil current increases to an excessive value (as is the case at coil saturation) extra charge is fed into the sweep capacitor $C_{SWF}$. As a result the frequency very quickly drops towards its minimum value and during this fast frequency decrease the lamp ignites earlier.

This drastically reduces the time that excessive current is flowing through the half-bridge FETs.

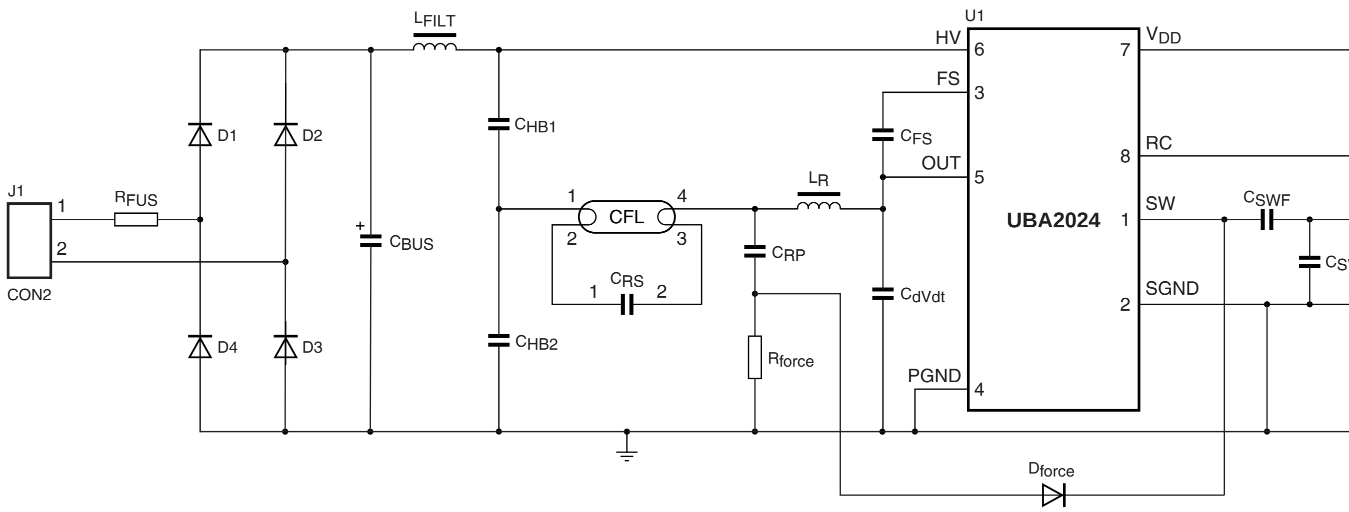
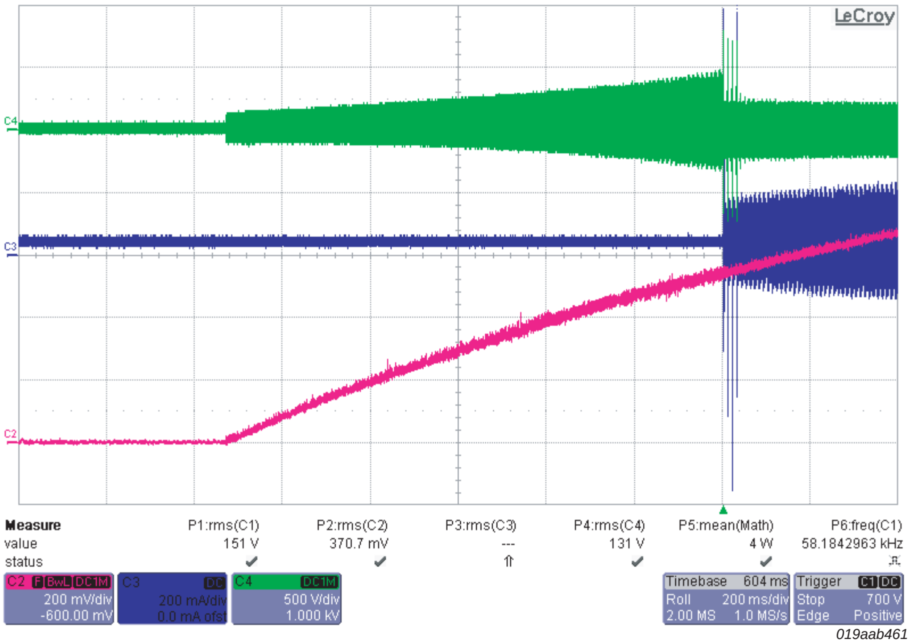
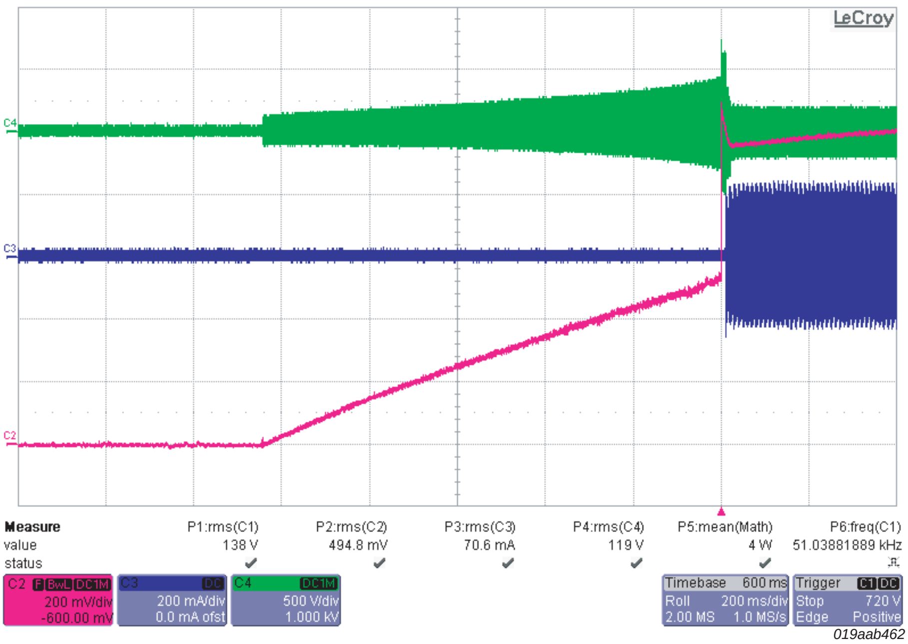



Fig 30. UBA2024 application with improved preheat and saturation protection

The resonant capacitor is split up in $C_{RS}$ and $C_{RP}$, so the total resonance capacitance equals $C_{RS}$ + $C_{RP}$. A part of the coil current also flows through $C_{RP}$ and this current is sensed by $R_{force}$. $C_{RP}$ and $R_{force}$ are chosen such that when the coil goes in to saturation, the voltage over $R_{force}$ exceeds the sum of the normal operating voltage on the SW pin and the forward voltage of $D_{force}$. If that is the case extra charge is fed into $C_{SW}$ and the IC will be immediately forced towards ignition. $D_{force}$ must be a low leakage diode.




a. Without $R_{force}$ and $D_{force}$

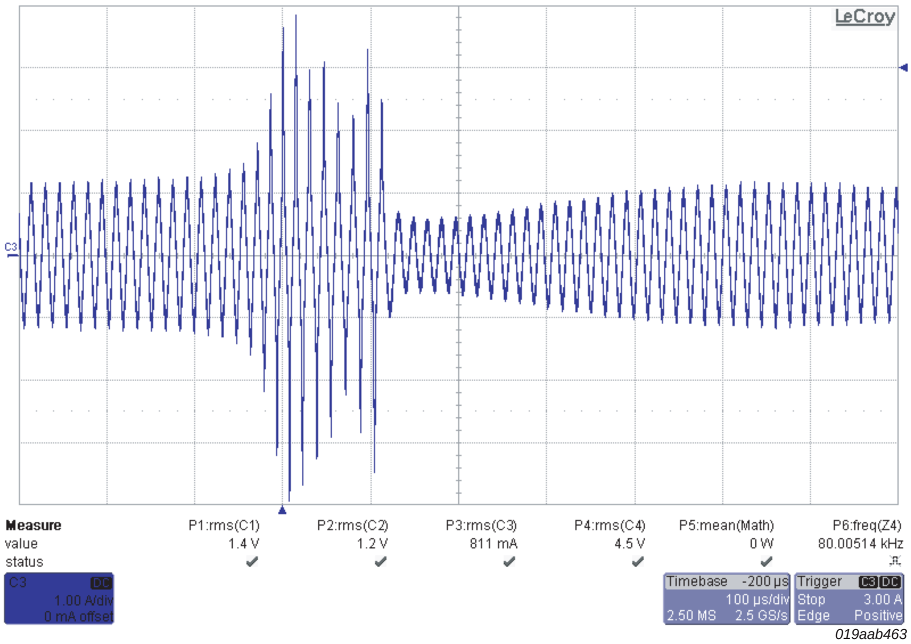



b. With $R_{force}$ and $D_{force}$

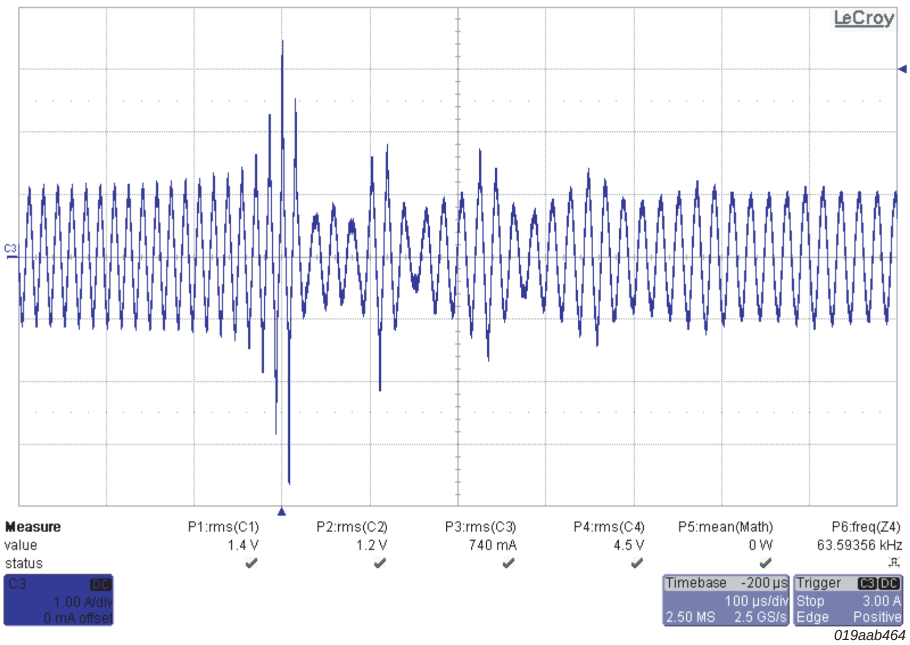
Trace legend: green = $V_{lamp}$, blue: $I_{lamp}$, pink: $V_{SW}$.

**Fig 31. Start-up of the application**

The waveforms during start-up are shown in Figure 31. The next figures will shown the inductor current during coil saturation in more detail.




a. Without $R_{force}$ and $D_{force}$




b. With $R_{force}$ and $D_{force}$

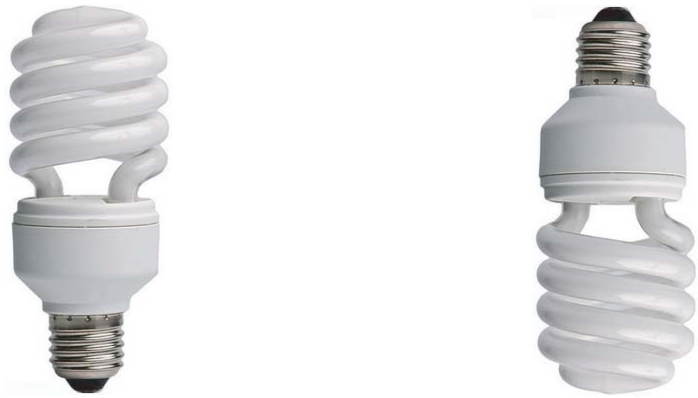
**Fig 32. Coil current during ignition**

It is clear that when the coil goes into saturation, several bursts of saturation current peaks can be observed, see Figure 31(a). The current peaks as shown in Figure 32(a) can reach very high values during several periods which can destroy the IC. Figure 32(b) shows the coil current for the same application with $R_{force}$ and $D_{force}$ installed.

The number of saturation current peaks has decreased significantly and the current's peaks are lower. In this way, the application can survive an extreme condition as described at the beginning of this section.

## 11. Thermal behavior

This section describes some measurements and results of thermal behavior of UBA2024AP and UBA2024AT reference PCB's in their actual 18 W CFL applications. The case temperature and ambient temperature were measured with thermocouples directly on the center of the IC package and 1 cm above the IC, respectively.



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a. Base UP position

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b. Base DOWN position

**Fig 33. CFL positions during measurements**

The first measurements are performed to get a reliable measurement of the junction temperature in the application. The tests are carried out in base up and base down positions (see Figure 33).

**Table 7. Temperatures in an application**

| IC and application | Base orientation | $P_{MAINS}$ (W) | IC | |
|---|---|---|---|---|
| | | | $T_{amb}$ (°C) | $T_{case}$ (°C) |
| UBA2024AP 230 V/18 W | up | 17.6 | 89 | 110 |
| | down | 15.9 | 68 | 86 |
| UBA2024AT 230 V/18 W | up | 17.8 | 86 | 103 |
| | down | 17.4 | 66 | 80 |

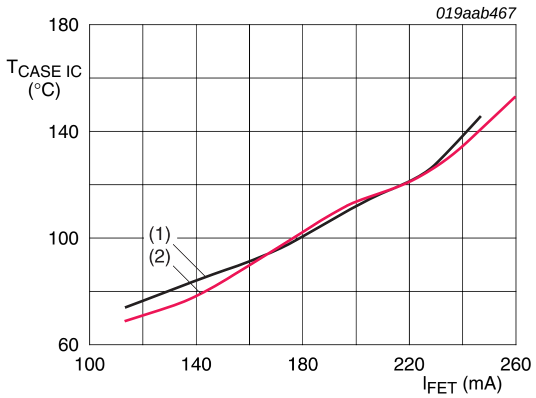
In the next measurement, the IC temperature is measured as a function of the half-bridge FET current. The current through the FET's is regulated by varying the mains voltage using a variac. The application was placed in a high hat in a base up position.

Table 8. UBA2024 IC case temperature as function of FET current

| $V_{MAINS}$ (V) | $I_{FET}$ (mA) | | $P_{MAINS}$ (W) | | $T_{case}$ (°C) | |
|---|---|---|---|---|---|---|
| | AP | AT | AP | AT | AP | AT |
| 150 | 113 | 113 | 10.4 | 10.8 | 74 | 69 |
| 175 | 142 | 139 | 13.2 | 13.8 | 85 | 78 |
| 200 | 169 | 168 | 15.2 | 16.4 | 95 | 95 |
| 230 | 202 | 196 | 17.5 | 19.2 | 113 | 112 |
| 260 | 232 | 225 | 19.6 | 21.6 | 128 | 124 |
| 285 | 260 | 247 | 21.5 | 23.6 | 153 | 146 |

The case temperature given in Table 8 is shown in a graphical representation in Figure 34.




(1) UBA2024AP.

(2) UBA2024AT.

Fig 34. IC case temperature as a function of half-bridge FET current

## 11.1 Junction temperature measurements

With MOSFETs, there is a good correlation between junction temperature and the on-state resistance of the switching device, the $R_{DSon}$. The resistance $R_{DSon}$ increases linearly over temperature and is representative of the junction temperature.
The multiplication factor of this increase depends on the process of the MOSFET and can be measured. The resistance increase per °C equals:

$$\frac{\Delta R}{\Delta T} = \frac{R_{DSon}@\ 150°C - R_{DSon}@\ 25°C}{150 - 25}[m\Omega/°C] \quad (6)$$

The correlation factor between temperature and the on-state resistance $R_{DSon}$ of the MOSFETs is identical for all EZ-HV MOSFETs and amounts 1.7 which means that:

$$R_{DSon}@\ 150°C = 1.7 \cdot R_{DSon}@\ 25°C \quad (7)$$

This correlation factor will be used for the calculations. The junction temperature will be calculated using Equation 8:

$$T_j = T_{amb} + \frac{(R_{DSon,\,operating} - R_{DSon,\,ambient})}{\Delta R / \Delta T} \qquad (8)$$

## 11.2 $R_{DSon}$ measurements in the CFL application

This section describes a method to measure the $R_{DSon}$ in a working application. The output voltage of the half-bridge $V_{OUT}$ has been measured during the time that the low-side MOSFET is on. At that moment $V_{OUT} = V_{DS}$ (Low Side). $V_{OUT}$ has a voltage range of approximately 325 V, so a voltage clamp is needed for an accurate measurement, see Figure 35.

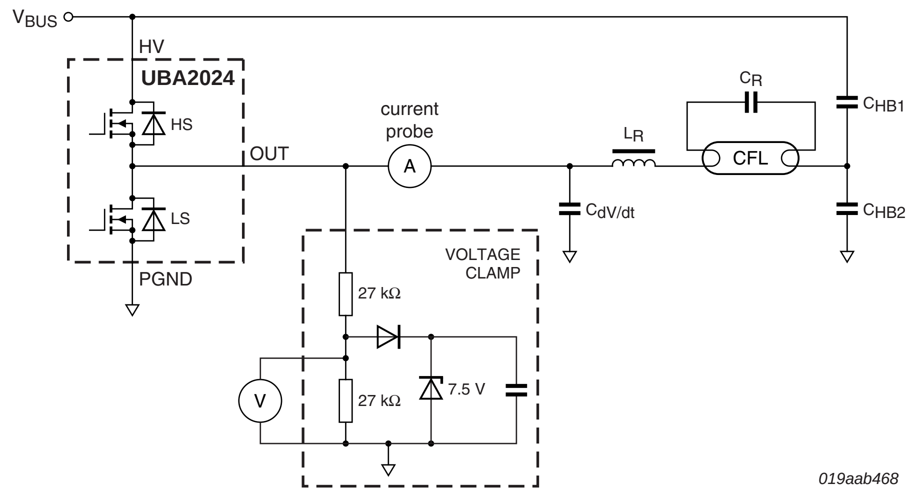



Fig 35. Application with a voltage clamp circuit

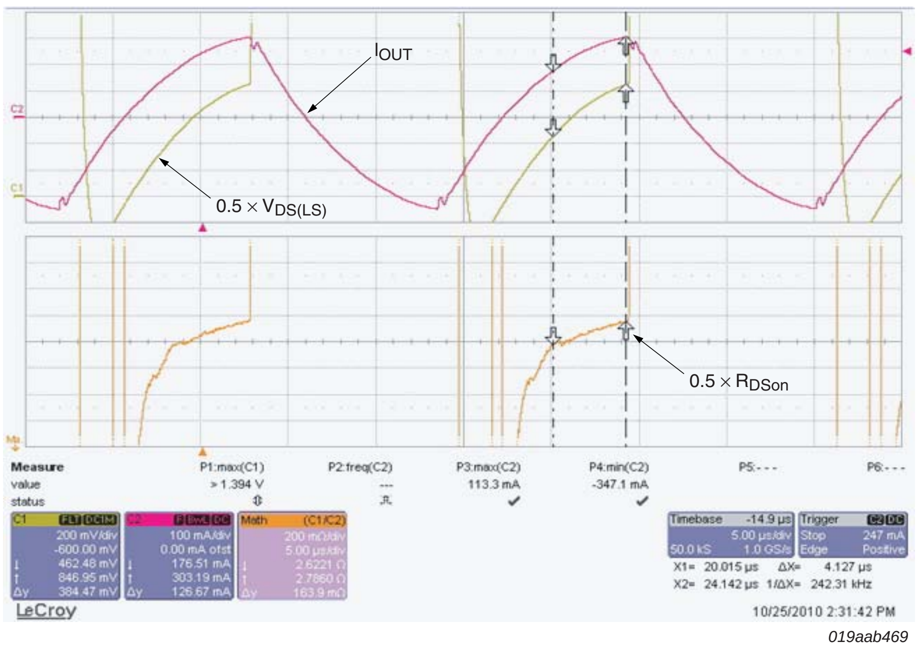



Fig 36. $R_{DSon}$ measurement at $T_j$ = 25 °C

The first measurement is performed immediately after the lamp has ignited where the package temperature is still equal to the ambient temperature of 25 °C. The junction temperature is supposed to be the same.

$V_{DS}$ of the low-side MOSFET is measured by means of a voltage clamp as shown in Figure 35. Actually $V_{DS}/2$ is measured, due to the 27 kΩ voltage divider in the clamp circuit. The current is measured through the OUT pin of the UBA2024. The actual $R_{DSon}$ is determined by the ratio of $V_{DS}$ and $I_{OUT}$. See Figure 36 and Figure 37.

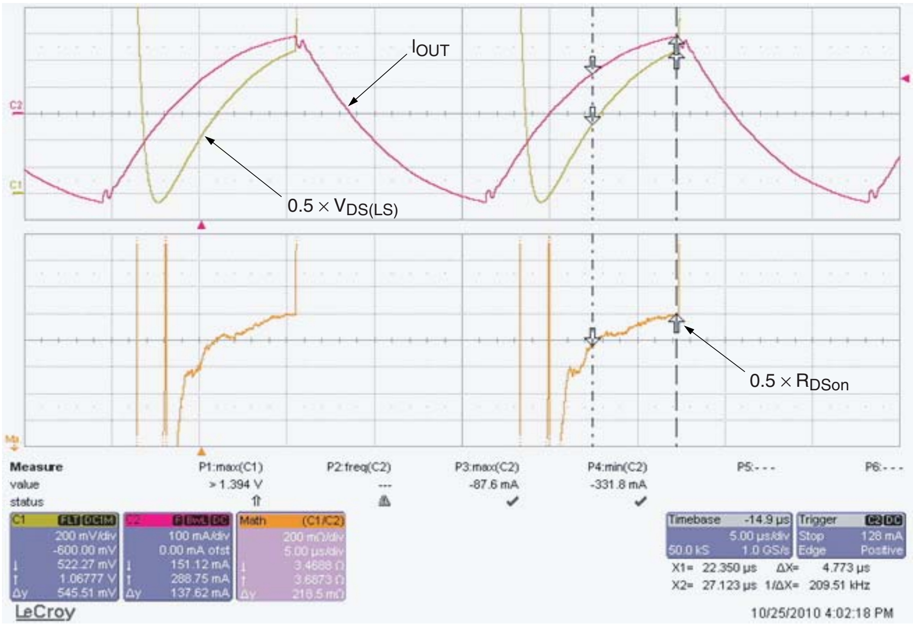



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**Fig 37. $R_{DSon}$ measurement at $T_j$ = 86 °C**

The measurement results shown in Figure 36 and Figure 37 are for a UBA2024AP (DIP8) 18 W, 230 V application in a base down position. The measured values and corresponding calculations can be found in the Appendix in section 5.

# 12. Measurement results $R_{DSon}$ and $T_j$ calculations

In this section, the results and calculations are given for the $R_{DSon}$ measurements and $T_j$ calculations for an 18 W 230 V application with the UBA2024AP (DIP8) and UBA2024AT (SO14).

## 12.1 Measurement on a UBA2024AP (DIP8) 18 W 230 V application

The measured $R_{DSon}$ at 25 °C equals 5.57 Ω, so at 150 °C the calculated maximum $R_{DSon}$ is 1.7 × 5.57 Ω = 9.47 Ω according to Equation 7. The increase of resistance per °C equals (9.47 – 5.57) / (150 – 25) = 31.22 mΩ/°C, according to Equation 6.

### 12.1.1 Operation in base down position

After an hour in operation in a base down position, the following data is measured: $T_{CASE}$ = 86 °C, $R_{DSon,operating}$ = 7.37 Ω, well below $R_{DSon,maximum}$. Now the junction temperature can be calculated, using Equation 8.

$$T_j = 25 + \frac{7.37 - 5.57}{31.22 \cdot 10^{-3}} = 83\ °C \tag{9}$$

### 12.1.2 Operation in base up position

After an hour in operation in a base up position, the following data is measured: $T_{CASE}$ = 110 °C, $R_{DSon,operating}$ = 7.92 Ω, well below $R_{DSon,maximum}$. Now the junction temperature can be calculated, using Equation 8.

$$T_j = 25 + \frac{7.92 - 5.57}{31.22 \cdot 10^{-3}} = 101\ °C \tag{10}$$

## 12.2 Measurement on a UBA2024AT (SO14) 18 W 230 V application

The measured $R_{DSon}$ at 25 °C equals 6.34 Ω, so at 150 °C the calculated maximum $R_{DSon}$ is 1.7 × 6.34 Ω = 10.77 Ω according to Equation 7. The increase of resistance per °C equals (10.77 – 6.34) / (150 – 25) = 34.22 mΩ/°C, according to Equation 6.

### 12.2.1 Operation in base down position

After an hour in operation in a base down position, the following data is measured: $T_{CASE}$ = 89 °C, $R_{DSon,operating}$ = 9.04 Ω, well below $R_{DSon,maximum}$. Now the junction temperature can be calculated, using Equation 8.

$$T_j = 25 + \frac{9.04 - 6.34}{35.45 \cdot 10^{-3}} = 101\ °C \tag{11}$$

### 12.2.2 Operation in base up position

After an hour in operation in a base up position, the following data is measured: $T_{CASE}$ = 111 °C, $R_{DSon,operating}$ = 9.24 Ω, well below $R_{DSon,maximum}$. Now the junction temperature can be calculated, using Equation 8.

$$T_j = 25 + \frac{9.24 - 6.34}{35.45 \cdot 10^{-3}} = 107\ °C \tag{12}$$

# 13. References

[1] **IEEE publication —** An Improved Design Procedure for LCC Resonant Filter of Dimmable Electronic.

[2] **Ballasts for Fluorescent Lamps, Based on Lamp Model —** Fabio Toshiaki Wakabayashi Carlos Alberto Canesin 2003.

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