AN10894

Application aspects of the UBA3070 switch mode LED driver

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Abstract	This document contains guidelines for the design and configuration of a UBA3070 IC switch mode LED driver application.

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1. Introduction

This document provides guidelines for the design and configuration of a UBA3070 switch mode current source application. The circuit of the UBA3070 demo board version 1.20 (see *UM10400*) is used as a starting point for all explanation and illustrations.

The UBA3070 IC is a controller for switch mode LED driver applications e.g. LED backlighting units for LCD TV and general lighting applications. A typical application for a UBA3070 IC is as a boundary mode buck converter which due to its fundamental properties operates as a switch mode current source. Refer to *AN10876* for further information.

2. Scope

This document is organized as follows:

- Section 3 provides detailed information on the principles of operation, an explanation of in-circuit current flow and current level detection. Also included is a list of typical application characteristics, a component table including typical component values.
- Section 4 provides detailed information about the purpose of key non-IC components, including equations for calculating their optimal values and reference examples.
- Section 5 provides detailed information about direct and indirect demagnetization (demag) detection.

3. Principles of operation

To fully understand the operation cycle and principles of in-circuit current flow refer to Figure 1 and Figure 2. Figure 1 shows the in-circuit current flow, Figure 2 shows the current waveform.

3.1 Operation cycle

1. When MOSFET Q1 is closed, the current in inductor L1 starts to rise linearly (red/outer line in Figure 1).
2. When I_{peak} is reached, Q1 is opened by the internal logic of the UBA3070 IC.
3. With L1 current continuing to flow through diode D3, the current now starts to decrease linearly.
4. When L1 current decreases to 0 A, Q1 is closed and the operation cycle repeats from 1.

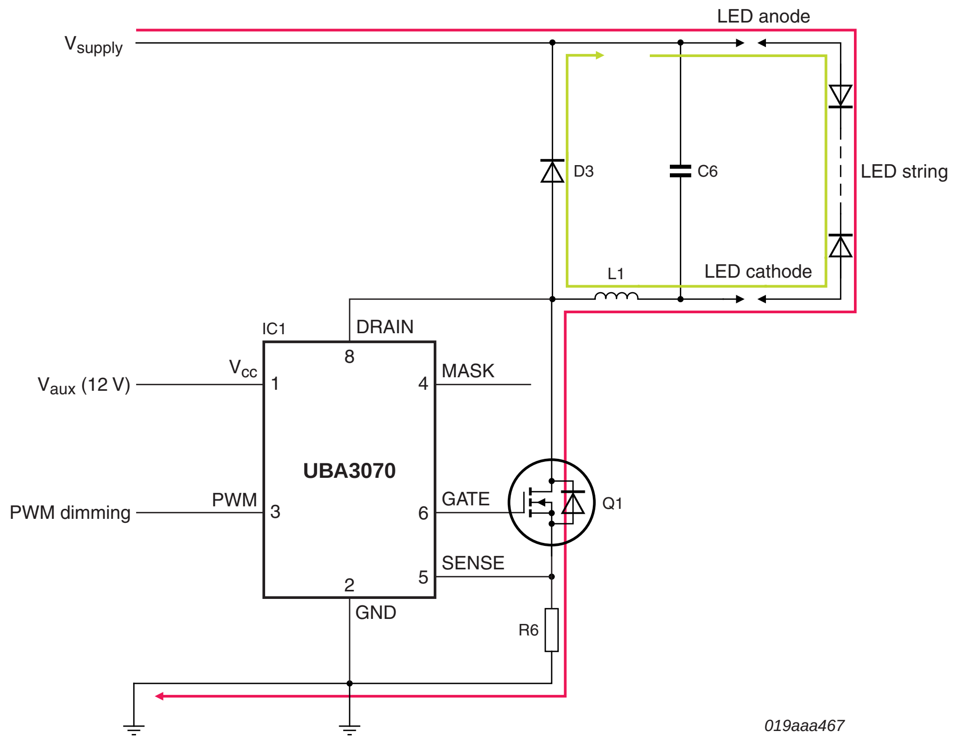

Fig 1. Current flow in a typical UBA3070 IC application

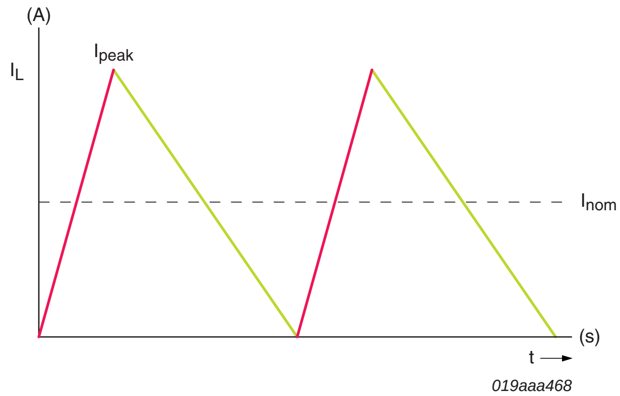

Fig 2. Inductor L1 current waveform

Figure 1 and Figure 2 show that the current rise and fall rates are constant due to the voltage drop across L1. They remain fixed during both the primary stroke (Q1 on-state) and the secondary stroke (Q1 off-state). Therefore, as there is no dead-time between cycles, the average current in L1 and in the LEDs is half of the value of I_{peak}.

Peak current level (I_{peak}) is detected during the primary stroke. As the current in sense resistor R6 is the same as the current in L1, the voltage drop across R6 is a measure for the inductor current. By feeding back the voltage drop across sense resistor R6 to the UBA3070 IC SENSE pin, the peak current level is detected. The default sense level on the SENSE pin is 0.52 V.

The zero current level (or L1 demagnetization) is detected at the end of the secondary stroke. The UBA3070 includes a design feature which allows the reporting of zero current when a voltage level of < 100 mV is present on the MASK pin. L1 is regarded to be demagnetized during such conditions.

Two options exist to transform the detection of L1 demagnetization into a precise signal for the MASK pin. The two options include:

- Direct demag detection. Explained in detail in Section 5.1
- Indirect demag detection. Explained in detail in Section 5.2

Figure 3 shows the full diagram of a UBA3070 application that uses the direct demag detection option. The current in L1 is mirrored and scaled by the asymmetric current mirror (Q2, Q3, R4, R7). The scaled current causes a voltage drop across R5, which is applied to the MASK pin after filtering.

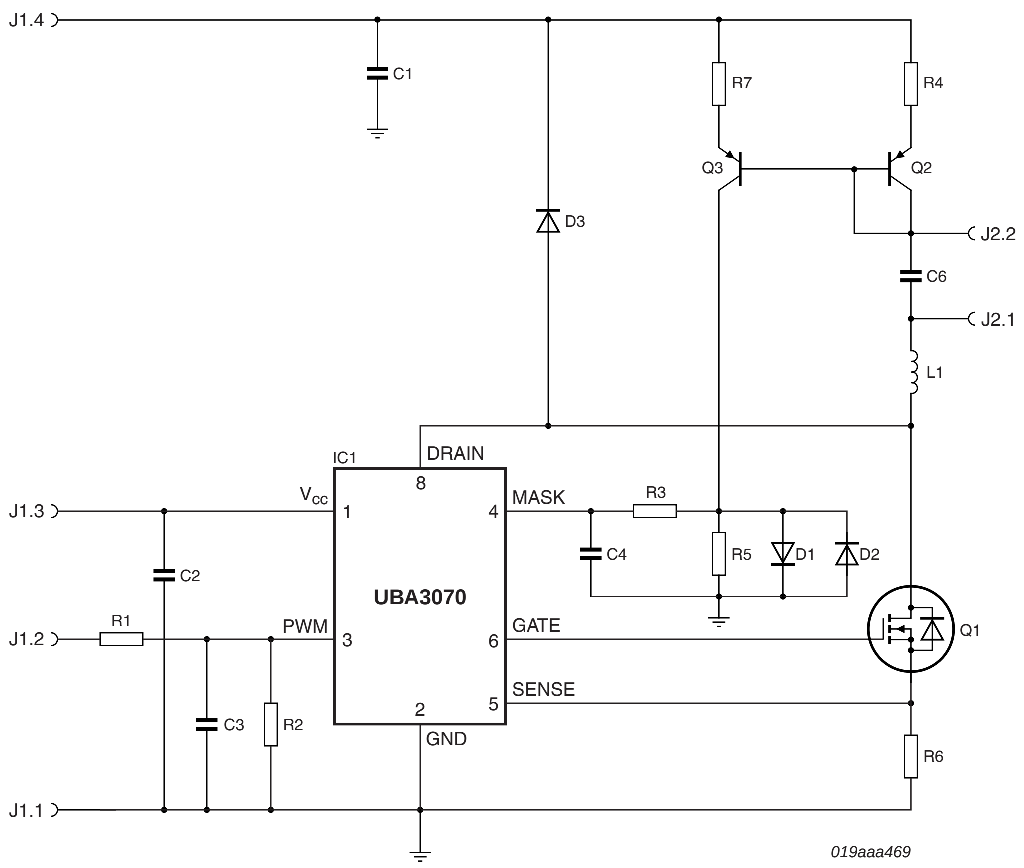

Fig 3. UBA3070 full circuit diagram (with direct demag detection)

Detailed below is a list of typical UBA3070 application characteristics.

- Output current: ~350 mA
- Maximum main supply voltage: 200 V (J1.1 = GND, J1.4 = V_{supply})
- Auxiliary voltage: 12 V (J1.1 = GND, J1.3 = V_{aux})

- LED string drive capability: maximum cumulative V_F voltage drop = 170 V (approximately 60 red LEDs or 45 green/blue/white series LEDs)

Detailed in Table 1 is list of components and values used in a typical UBA3070 application. Refer to Figure 3.

Table 1. Component list

Reference	Component	Remark
IC1	UBA3070	NXP Semiconductors
Q1	PHD9NQ20T	NXP Semiconductors; varies with implementation
Q2	BCP51	NXP Semiconductors
Q3	BF723	NXP Semiconductors; varies with implementation
D1	BAS316	NXP Semiconductors
D2	BAS316	NXP Semiconductors
D3	BYG20J	Vishay
C1	22 μF, 200 V	varies with implementation
C2	100 μF, 25 V	-
C3	180 pF	-
C4	22 pF	-
C6	100 nF, 250 V	varies with implementation
L1	560 μH, 700 mA	varies with implementation
R1	1 kΩ, 0.125 W	-
R2	10 kΩ, 0.125 W	-
R3	22 kΩ, 0.125 W	-
R4	0.75 Ω, 0.25 W	varies with implementation
R5	10 kΩ, 0.125 W	-
R6	0.75 Ω, 0.25 W	varies with implementation (sense resistor)
R7	510 Ω, 0.125 W	-

4. Component selection

Section 4.1 to Section 4.3 states the purpose of key non-IC components used in typical UBA3070 applications. The equations and examples are provided to identify the relationship between circuit components, key circuit values and component selection. Refer to Figure 3.

4.1 Selecting resistor R6

Sense resistor R6 determines the peak current that will flow through the LED string. The operating cycle was described in Section 3.1.

The relationship between the average (or nominal) LED current and R6 can be calculated using equations Equation 1 and Equation 2:

$$I_{LED} = \frac{I_{peak}}{2} = \frac{V_{peak}}{2 \cdot R6} = \frac{0.26}{R6} \quad (1)$$

$$R6 = \frac{V_{peak}}{2 \cdot I_{LED}} = \frac{0.26}{I_{LED}} \quad (2)$$

Second order effects may require the adjustment of R6 by up to 10 % (up to 10 % lower than calculated using Equation 2). R6 must be selected with sufficient power handling capability.

Example: Under optimal design conditions the current through the LED string (of arbitrary length) must be 350 mA. The value of R6 can be calculated using Equation 3:

$$R6 = \frac{0.26}{I_{LED}} = \frac{0.26}{0.35} \approx 0.75\Omega \quad (3)$$

The input voltage for the circuit (V_{supply} in Figure 1) must be at least 20 % higher (a factor of 1.20) than the cumulative nominal voltage drop across the LED string, e.g. a string of 30 white LEDs with a nominal voltage drop of 3.3 V at 350 mA must be supplied by V_{supply} of at least = 1.2 (30 × 3.3) = 120 V.

4.2 Selecting inductor L1

Inductor L1 determines the conversion frequency. The conversion frequency of the LED driver is intended to be in the 100 kHz range for the following reasons:

- In-chip technology requires the maximum switching frequency to be lower than 145 kHz
- The considerable current loop length (multiple LEDs in series) and the LED ripple current impose ElectroMagnetic Interference (EMI) restrictions. Regulations (legislation) require sufficient separation from the 150 kHz EMI mask frequency.

Charging time of L1 is given by Equation 4:

$$t_c = L_1 \times \frac{2 \times I_{LED}}{V_{supply} - V_{LED}} \quad (4)$$

In the example shown in Figure 3, let's assume that the supply voltage (V_{supply}, connected between J1.4 and J1.1) is 170 V. For 30 white LEDs (V_F for each element is approximately 3.3 V), the voltage drop across the LED string (V_{LED}) would be 100 V (at 350 mA LED current).

Discharging time of L1 is given by Equation 5:

$$t_d = L_1 \times \frac{2 \times I_{LED}}{V_{LED}} \quad (5)$$

As a result the switching frequency is given by Equation 6:

$$f_{sw} = \frac{1}{t_c + t_d} \quad (6)$$

If L1 has a value of 560 μH, the switching frequency would be approximately 105 kHz.

At a given main supply voltage and a given LED current, the maximum switching frequency is achieved when $t_c = t_d$. This condition occurs when the LED string voltage is half of the supply voltage, see Equation 7:

$$V_{LED} = \frac{t_c}{t_c + t_d} \cdot V_{supply} = \frac{V_{supply}}{2} \quad (7)$$

In cases of variable load where the main supply voltage and LED current is fixed, L1 must be chosen so that the maximum allowable switching frequency of the UBA3070 IC can never be exceeded.

Figure 4 shows a normalized graph of f_{sw} versus V_{LED} / V_{supply}.

If a maximum switching frequency f_{sw} = 145 kHz is required, then the smallest possible inductance value can be calculated using Equation 8:

$$L_1 = \frac{V_{supply}}{8 \cdot f_{sw} \cdot I_{LED}} = \frac{1}{1160000} \cdot \frac{V_{supply}}{I_{LED}} \quad (8)$$

When V_{supply} = 170 V and I_{LED} = 350 mA, the smallest possible L1 would be 418 μH.

Furthermore, L1 must be chosen with a suitable saturation current (i.e. > 2 × I_{LED}), 145 kHz operation capability and with good power dissipation capabilities.

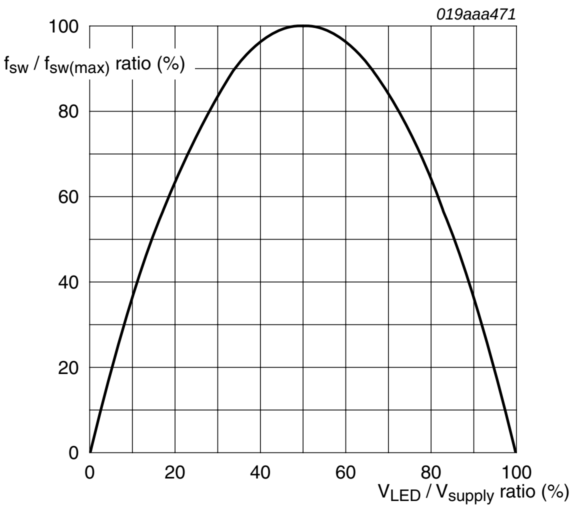

Fig 4. Normalized UBA3070 switching frequency

4.3 Selecting capacitor C6

Capacitor C6 determines the filtering of the coil current to reach acceptable ripple current through the LEDs. In addition, C6 also determines the rise and fall current tails during switch-on and switch-off of the converter. Turning the converter on and off, is the method used for Pulse-Width Modulation (PWM) dimming. Furthermore, C6 must be chosen carefully, trading-off ripple, tailing requirements and dimming range.

The dynamic resistance of the LED string needs to be used for making a first estimate:

$$Ripple\_percentage = \frac{1}{\pi \times R_{dyn(LED)} \times C6 \times f_{sw}} \quad (9)$$

$$C6 = \frac{1}{\pi \times R_{dyn(LED)} \times Ripple\_percentage \times f_{sw}} \quad (10)$$

with

$$R_{dyn(LED)} = \frac{\partial V_{LED}}{\partial I_{LED}} at\ nominal\ I_{LED} \quad (11)$$

Ripple percentage (alternatively, ripple factor) is defined as the peak-to-peak value of the ripple current amplitude divided by the DC (nominal) current value.

Example: Consider an LED string of 30 white LEDs. The average target current through the LEDs is 350 mA. At 350 mA the voltage drop across one LED is 3.3 V and at 351 mA, the voltage drop is 3.31 V. The approximate $R_{dyn\ (LED)}$ is given in Equation 12:

$$R_{dyn(LED)} = \frac{\partial V_{LED}}{\partial I_{LED}} = \frac{30 \times (3.31 - 3.3)}{0.351 - 0.350} = 300\Omega \quad (12)$$

Allowing a 10 % ripple (a factor of 0.10) on the current through the LEDs and a switching frequency of 105 kHz, then C6 can be calculated using Equation 13:

$$C6 = \frac{1}{\pi \cdot 300 \cdot 0.10 \cdot 105000} \approx 101nF \quad (13)$$

5. Demagnetization (demag) detection circuits

Various demag detection options can be employed. Two options that are practically feasible are discussed: direct and indirect demag detection. Though the circuit design and the components used are slightly different, the purpose of both circuits is to provide/generate a precise signal about the magnetization status of L1 to the UBA3070 MASK pin. Each demag detection option is explained in Section 5.1 and Section 5.2.

5.1 Direct demag detection

Direct demag detection is the default mode and the most accurate detection option when a high level of LED current accuracy is required. Figure 3 shows a typical direct demag detection circuit is built around an asymmetric current mirror comprising Q2, R4, Q3 and R7 which senses the current through L1 then translates the sensed current level it into a voltage signal using R5. The voltage is limited to ± 0.7 V by the anti-parallel diodes D1 and D2. The current flow into the MASK pin is limited by resistor R3 with capacitor C4 managing some of the noise rejection.

In order to maintain high efficiency, the mirrored current (I_{MR}) must only be a fraction of the current through L1. However, the mirrored current must not be too small in order to obtain sufficient noise immunity. A few hundred μA in the mirrored branch is typically a good compromise. A mirrored current of approximately 500 μA is assumed for the remainder of this section.

$$I_{MR} = 500\mu A \quad (14)$$

The bipolar PNP transistors Q2 and Q3 should preferably both have high h_{FE} figures. In addition, Q2 must be capable of handling 2 × I_{LED} collector current, while the maximum operating voltage of the transistor can be low e.g. < 20 V. Transistor Q3 must be capable of withstanding V_{supply} between collector and emitter, while the maximum operating current can be low (at least 2 × I_{MR}).

Table 2. Suggested Q2 bipolar transistors

I_{LED}	Q2 transistor type
≤ 250 mA	BCX17, BCX18
250 mA to 500 mA	BCX51, BCX52, BCX53
500 mA to 1 A	PBSS5320X
1 A to 2 A	PBSS5520X, PBSS301PZ

Table 3. Suggested Q3 bipolar transistors

V_{supply}	Q3 transistor type
≤ 50 V	BC856
50 V to 100 V	BSS63, PMBT5401
100 V to 200 V	BF623, BF723, BF823, PXTA92
200 V to 500 V	PBHV9040T

The operation of the current mirror Q2/Q3 is more accurate when the voltage drop across the mirror resistors R4/R7 is larger. However, a higher voltage drop leads to higher power loss and lower efficiency of the circuit. A workable compromise for V_{MR} in relation to I_{LED} is detailed in Table 4.

Table 4. Suggested I_{LED} dependent V_{MR} values

Nominal LED current I_{LED}	Suggested V_{MR}	R4 power rating
≤ 350 mA	250 mV	0.25 W
350 mA to 700 mA	150 mV	0.5 W
700 mA to 1.5 A	100 mV	0.5 W

With V_{MR}. I_{MR} and I_{LED} known, the direct demag detection circuit component values can be calculated using Equation 15 Equation 16 and Equation 17:

$$R4 = \frac{V_{MR}}{I_{LED}} \quad (15)$$

$$R7 = \frac{V_{MR}}{I_{MR}} \quad (16)$$

$$R5 = \frac{5.0}{I_{MR}} \quad (17)$$

In-circuit components of fixed value are detailed in Table 5.

Table 5. Fixed components in the direct demag detection circuit

Component	Value
D1, D2	BAS316, 1N4148, BAV99 (dual diode) or equivalent
R3	22 kΩ
C4	22 pF

5.1.1 Calculating component values

Given that the nominal programmed LED current (I_{LED}) is 350 mA and that the operating voltage (V_{supply}) is 170 V. From Table 2 and Table 3, Q2 and Q3 are selected as BCX53 and PXTA92 respectively and a value for V_{MR} from Table 4 as:

$$V_{MR} = 0.25V \tag{18}$$

The values for resistors R4, R7 and R5 can be calculated using Equation 15, Equation 16 and Equation 17:

$$R_4 = \frac{V_{MR}}{I_{LED}} = \frac{0.5}{0.35} = 0.71\Omega \tag{19}$$

$$R_7 = \frac{V_{MR}}{I_{MR}} = \frac{0.25}{0.0005} = 500\Omega \tag{20}$$

$$R_5 = \frac{5.0}{I_{MR}} = \frac{5.0}{0.0005} = 10000\Omega \tag{21}$$

5.2 Indirect demag detection

Indirect demag detection is the least accurate detection option when high levels of LED current accuracy is required. Figure 5 shows a typical indirect demag detection circuit that uses the ringing of the drain node of MOSFET Q1 as an indication of L1 losing it’s energy. The ringing signal propagates through C9 and R10 and the first valley of the signal forces the voltage on the MASK pin to drop below 100 mV. For the UBA3070 this is the indication that a new cycle must start, refer to Section 3.1.

The ringing signal contributes to the less accurate nature of this detection option. In addition, other switching signals can be misinterpreted by this circuit configuration (as an indication of the inductor becoming energy-less) causing inaccurate current control. For example, PWM dimming can cause additional signals appearing on the drain node of Q1 that interfere with accurate current control. Therefore, applications that require a high level of LED current accuracy and where PWM dimming is used, indirect demag detection may not be the optimal option.

The component configuration for this detection option can also be implemented on the UBA3070 V1.2 demo board. Table 6 shows the component changes with respect to the Bill Of Materials (BOM) shown in (Table 1).

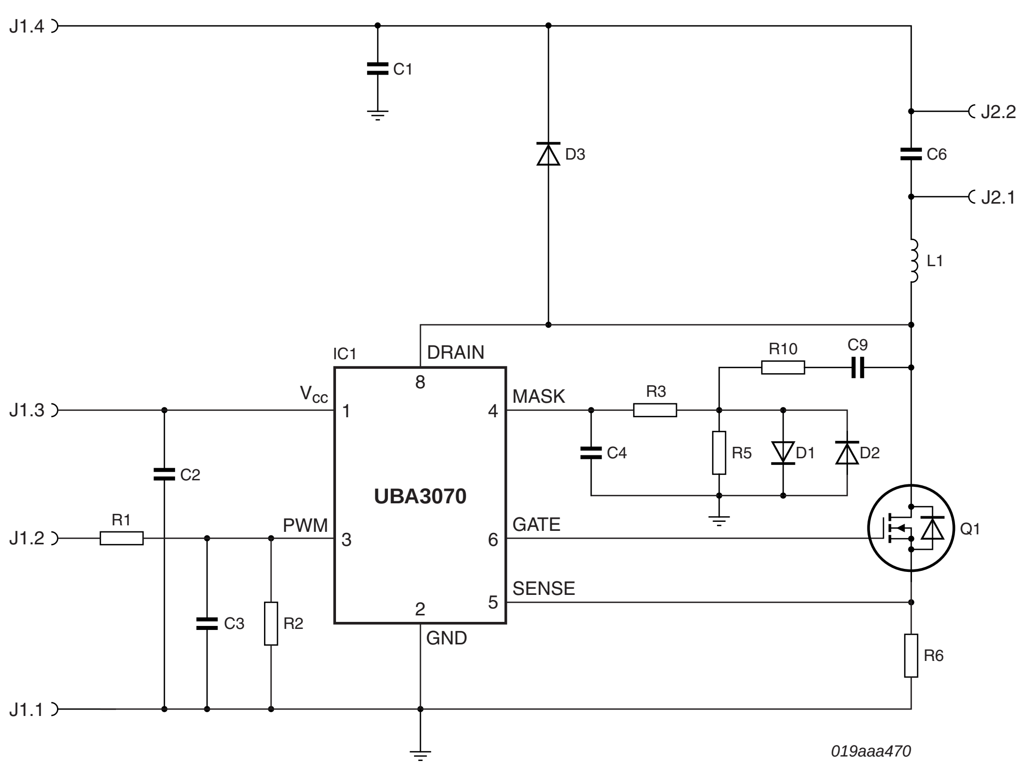

Fig 5. UBA3070 full circuit diagram (with indirect demag detection)

Table 6. List of component changes

Reference	Value (typical)	Remark
Q2	not mounted	-
Q3	not mounted	-
C9	330 pF, 200 V	-
R4	not mounted	-
R5	1 kΩ	-
R7	not mounted	-
R10	22 kΩ, 0.125 W	-

6. Abbreviations

Table 7. Abbreviations

Acronym	Description
BOM	Bill Of Materials
EMI	ElectroMagnetic Interference
IC	Integrated Circuit
LCD	Liquid Crystal Display
LED	Light Emitting Diode
PNP	Positive Negative Positive
MOSFET	Metal-Oxide Semiconductor Field Effect Transistor
PWM	Pulse-Width Modulation

7. References

[1] **UBA3070 —** Data sheet

[2] **UM10436 —** User manual

[3] **AN10876 —** Buck converters for SSL application note

8. Legal information

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9. Tables

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