The frequency of the pre-regulator stage and the contrast regulator stage are synchronized with the inverter circuit which share a common oscillator. This feature helps to reduce possible RFI and the effect of the "walking" lines across the LCD screen. The operating frequency of the buck and the contrast regulator is twice that of the CCFL current frequency.

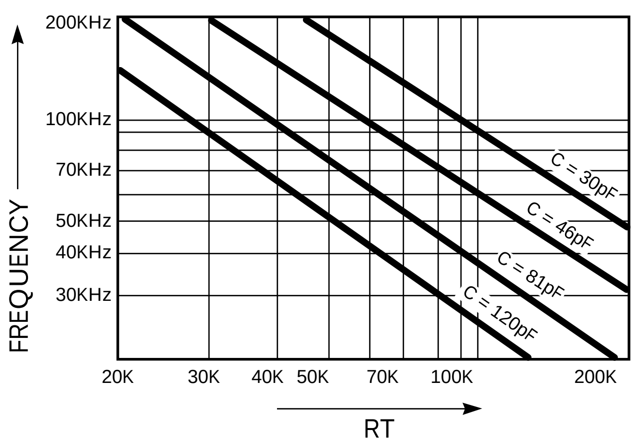


Figure 2. R_T and C_T Selection to Set Frequency for ML4874.

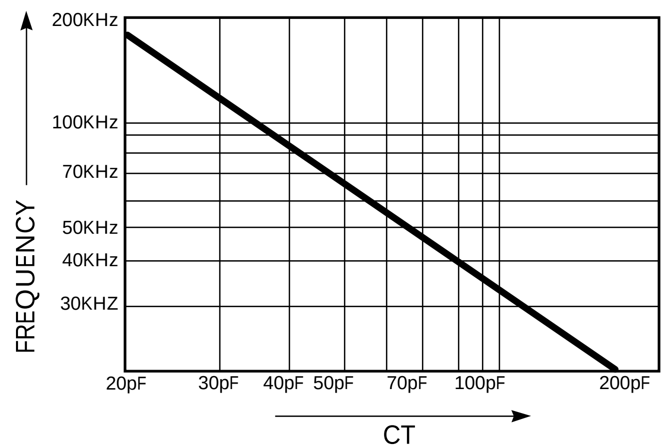


Figure 4. C_T Selection to Set Frequency for ML4876.

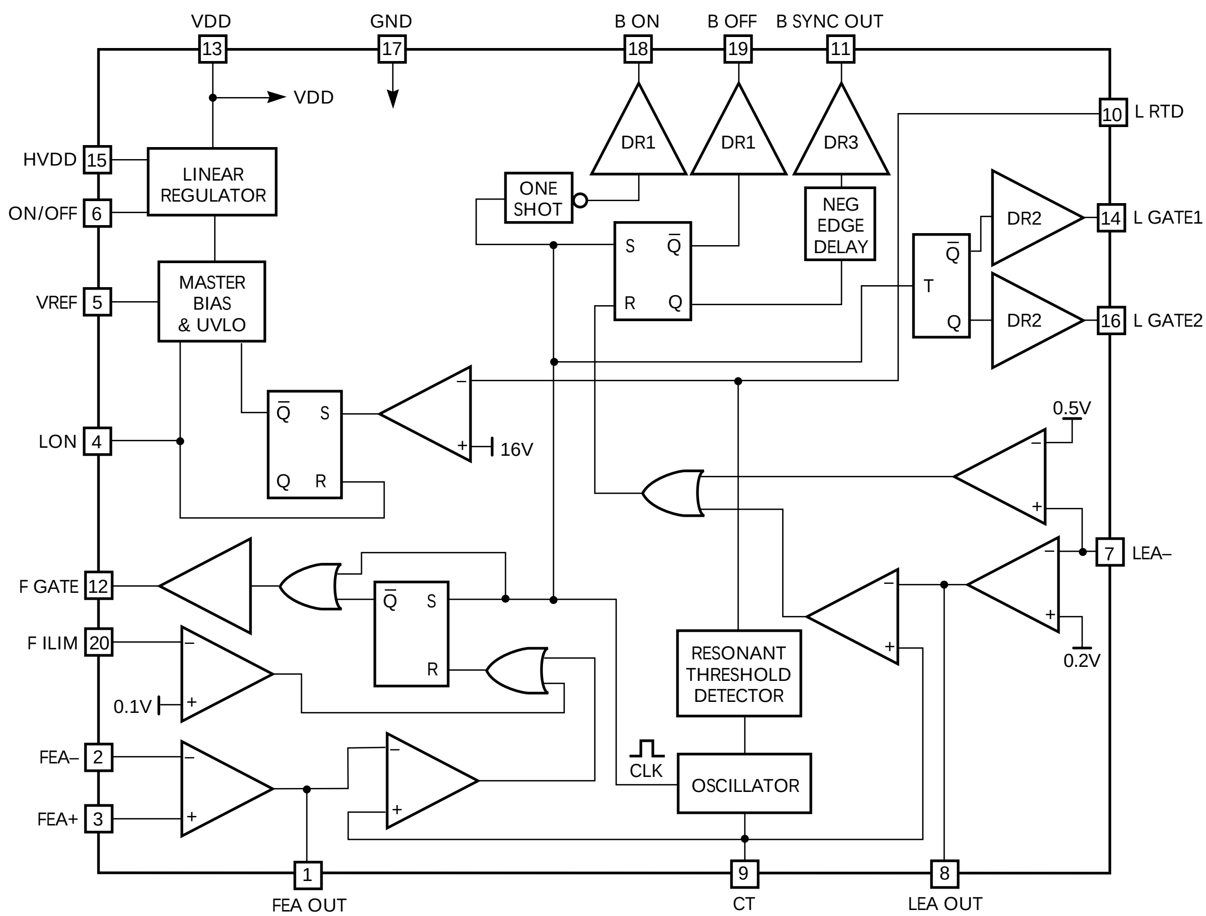


Figure 3. Block Diagram of ML4876.

SIMILARITIES AND DIFFERENCES BETWEEN THE ML4874 AND THE ML4876

Similarities

They are both high-efficiency differential backlight drivers, with low standby current (<10µA).

The buck regulator with synchronous rectification and resonant threshold detection are also common features.

Differences

The basic differences between the two controllers are tabulated below:

ML4874	ML4876
No Contrast	Contrast Control
Zener (Pin 2)	No Zener
R_T and C_T Pins	Only C_T Pin
Separate input for lamp current feedback and current limit	Both functions share one pin
L_{ON} pin for lamp only	L_{ON} and ON/OFF pins
Soft Start Pin	No Soft Start

DESCRIPTION OF THE LAMP INVERTER CIRCUIT

The lamp inverter circuit is comprised of the current regulating buck converter and the current-fed Royer-type inverter. The buck converter controls the magnitude of lamp current. This feature is instrumental in providing dimming control. The simplified equivalent electrical schematic of the driver section is shown in Figure 5. Due to the presence of L_1, the circuit shown in Figure 5 is essentially a current fed parallel loaded parallel resonant circuit, which can be further simplified to that shown in Figure 6.

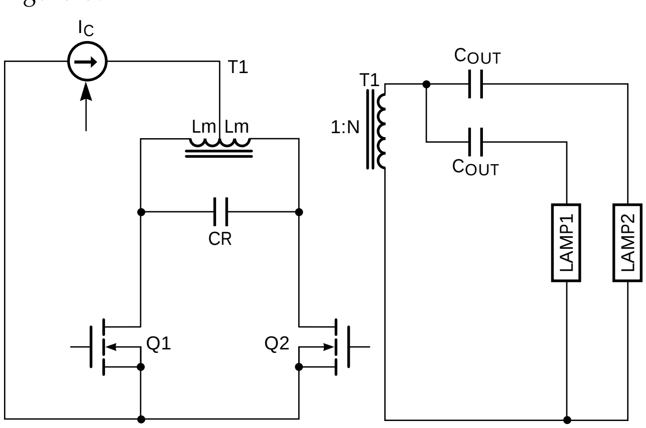


Figure 5. Simplified Lamp Driver Circuit.

The simplification in Figure 6 assumes that two lamps are operating in parallel. If one lamp is used then the original output ballast capacitor value should be used in the calculations.

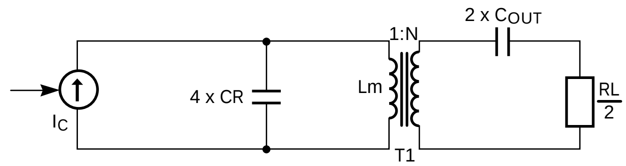


Figure 6. Simplified Lamp Driver Circuit.

L_m is the magnetizing inductance of the inverter transformer, which tunes with the resonant capacitor C_R to set the resonant frequency of the inverter. The oscillator frequency of the ML874/76 is set lower than the resonant frequency to ensure synchronization.

The current source labeled I_C in Figure 6 is a conceptual current source which models the function of L_1. Since the circuit always operates at resonance the impedance seen by the above current source is resistive and equal to the transformed impedance of the lamp which is given by the formula below:

$$R_L = \frac{V_L}{I_L} \qquad (1)$$

where V_L is the operating voltage of the lamp at full brightness and I_L is the lamp current.

In most cases the value of the ballasting capacitor C_{OUT} is chosen such that its reactance is approximately equal to the lamp resistance R_L. The two capacitors C_{OUT} are used to simulate two separate current sources, so that current will share between the lamps. The typical value for R_L is 100KΩ. For a typical operating frequency of 50kHz, C_{OUT} yields a capacitive reactance of approximately 100K. The best choice for this capacitor therefore lies between 27 to 33pF.

OPERATING WAVEFORMS OF THE LAMP DRIVER SECTION

Figure 7 shows some of the waveforms present in critical parts of the circuit. Refer to Figure 8.

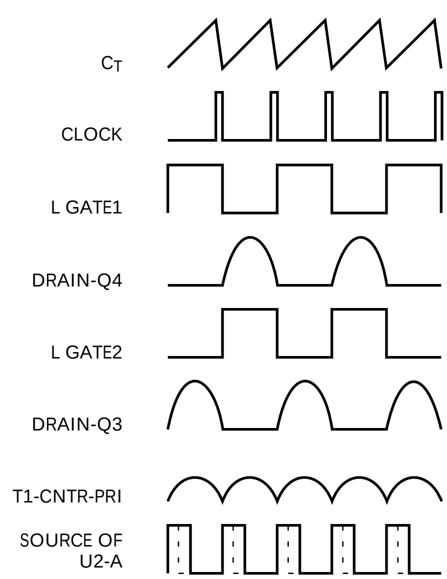


Figure 7. Operating Waveforms of the Lamp Driver Section.

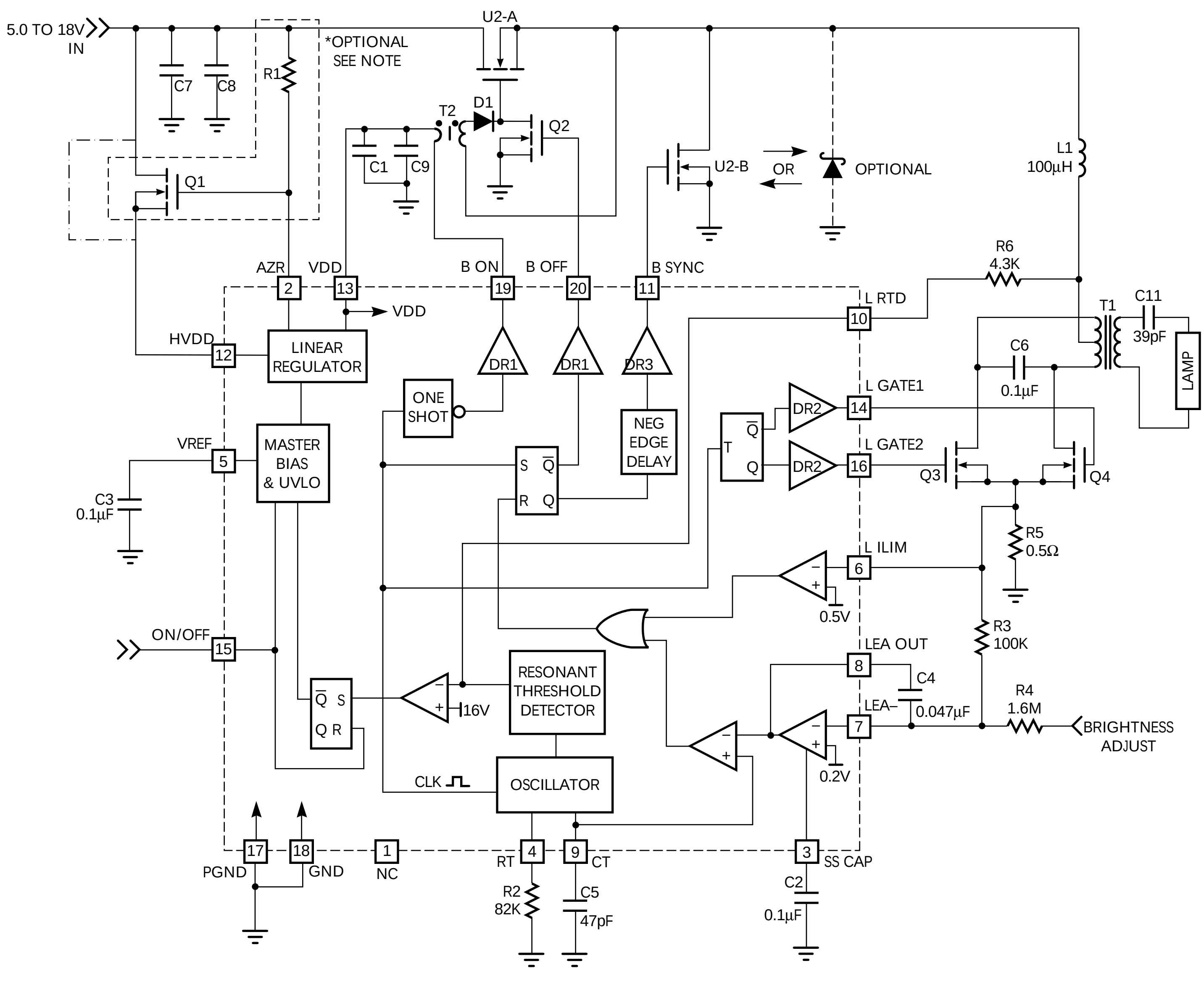
OSCILLATOR

The oscillator frequency is set externally through R_T and C_T for ML4874, and C_T only for ML4876 (R_T is a resistor of 82KΩ integrated on the chip). The equation below gives the relationship between frequency and timing components. This frequency should be set below the resonant frequency of the inverter. See Figures 2, 4 and 8.

$$f_{OSC} = \frac{1}{3.51 R_T C_T} \qquad (2)$$

Under steady state conditions, the oscillator frequency will be locked to twice the natural frequency of the lamp inverter resonant frequency. The lower bound on the resonant frequency (that will be used to calculate the oscillator timing components) can be calculated by using the following formula:

$$f_{MIN} \cong \frac{1}{2\pi\sqrt{L_m\left(4\,C_R + n\,N^2\,C_{OUT}\right)}} \qquad (3)$$



*NOTE: USED FOR INPUT VOLTAGES GREATER THAN 18 VOLTS

Figure 8. Typical Application Schematic for the ML4874.

Where n is the number of lamps at the output with ballasting capacitors C_{OUT}, N is the secondary to primary turns ratio of T_1, L_m is the primary inductance of T_1 and C_R is the capacitance across the primary. Based on this information the oscillator free running frequency is set to approximately 10% to 15% lower than twice the minimum frequency of the resonant tank.

$$C_T \cong \frac{\sqrt{L_m\left(4\,C_R + n\,N^2\,C_{OUT}\right)}}{R_T} \qquad (4)$$

$$R_T \cong \frac{\sqrt{L_m\left(4\,C_R + n\,N^2\,C_{OUT}\right)}}{C_T} \qquad (5)$$

Example Calculation for ML4874:

$L_m = 12 \times 10^{-6}$ $\qquad C_R = 0.1 \times 10^{-6}$

$C_T = 47 \times 10^{-12}$ $\qquad n = 1$

$C_{OUT} = 39 \times 10^{-12}$ $\qquad N = 135$

$$f = \frac{1}{2\pi\sqrt{L_m\left(4\,C_R + n\,N^2\,C_{OUT}\right)}} = 43\,\text{kHz} \qquad (6a)$$

$$R_T = \frac{\sqrt{L_m\left(4\,C_R + n\,N^2\,C_{OUT}\right)}}{C_T} = 78\,\text{k}\Omega \qquad (6b)$$

The natural frequency of the resonant tank will increase as the lamp(s) are dimmed. The upper bound of this increase can be estimated by the formula below:

$$f_{MAX} \cong \frac{1}{4\pi\sqrt{L_m\,C_R}} \qquad (7)$$

For the previous example this will be:

$L_m = 12 \times 10^{-6}$ $\qquad C_m = 0.1 \times 10^{-6}$

$$f_{MAX} \cong \frac{1}{4\pi\sqrt{L_m\,C_R}} = 72\,\text{kHz} \qquad (8)$$

Thus the lowest operating frequency will be at full brightness.

REFERENCE VOLTAGE

The reference voltage is 2.5 volts ±2%. To guard against noise, it is advisable to connect a 0.1µF capacitor across the reference to ground. This precise reference voltage helps to stabilize the brightness and contrast from unit to unit.

BUCK REGULATOR AND GATE DRIVE CIRCUIT

The ML4874/76 design is based on a 5V BiCMOS process to obtain the highest possible efficiency and size economy. The buck converter power MOSFET switch, U_{2A} is driven by a special gate drive circuit (see Figure 14).

This drive circuit consists of T_2, D_2 and Q_3. T_2 has the dual function of isolating the drive signal and stepping up its voltage for adequate enhancement of U_{2A}. T_2 is a standard surface mount transformer that can be obtained from many coil manufacturers. The ML4874/76 has been designed such that a short duration (approx. 150ns) voltage pulse is applied to T_2. This pulse charges the gate of U_{2A}. The charge is trapped at the gate by D_2 until the end of the ON-time at which point the gate of U_{2A} is discharged by Q_3. This drive technique enables the ML4874/76 to control power at voltages that are higher than its own maximum operating voltage rating of 5V.

The gate drive transformer requirements are listed below:

- Leakage inductance <300nH
- Primary magnetizing inductance >3µH.

SELECTION OF THE BUCK INDUCTOR (L1)

The inductor plays a central role in the proper operation of the inverter circuit.

To find the inductor value it is necessary to consider the inductor ripple current. The following formula gives the inductor peak to peak current ripple for when $V_{TP}<V_{IN}$.

$$i_{Lp-p} = \frac{V_{tp}}{2\pi f_{OSC}\,L_B}\left[1 + \text{COS}\left(2\frac{V_{TP}}{V_{IN}}\right)\right] \text{For } V_{TP} < V_{IN} \qquad (9)$$

Where: i_{Lp-p} is the peak to peak inductor current, V_{IN} is the supply voltage, V_{TP} is the peak voltage at the tab of T_1 (the waveform at this point is a full wave rectified sinewave), f_{OSC} is the inverter operating frequency, and L_B is the inductance of the buck regulator.

Normally the inductor peak to peak ripple current is chosen to be a small fraction of the overall DC current level. However, the circuit continues to function adequately, when this ripple is as large as the DC current. Ripple currents larger than the DC current will lead to larger-sized inductors due to the high peak currents with large ripple.

If we define the percentage of ripple in the inductor as:

$\%\ \text{ripple} = \frac{i_{Lp-p}}{i_{Lave}}$, then L_B is given by the following equation.

$$L_B = \frac{1}{\%\ \text{ripple}} \times \frac{{V_{TP}}^2}{\sqrt{2}\,2\pi\,f_{OSC\,MIN}\,P_{LMAX}} \times \left[1 + \text{COS}\left(\frac{2V_{TP}}{V_{IN\,MAX}}\right)\right] \qquad (10)$$

Where: P_L is the maximum lamp power (if more than one lamp is used then P_L is the total consumption of all the lamps). The above equation is set up to give the worst case value for L_B. Choosing % ripple to be 66% minimizes the LI^2 rating for the inductor.

Example:

$V_{IN\ MAX}$ = 12 Volts, P_L = 2 Watts

$f_{OSC\ MIN}$ = 55 kHz, V_{TP} = 7.2 Volts

$$L_B = \frac{(7.2V)^2}{0.66 \times 2\pi \times \sqrt{2} \times 55kHz \times 2W}\left[1 + COS\left(2\frac{7.2V}{12V}\right)\right] \quad (11)$$

$$= 109\mu H$$

In this case the calculated inductor value is 109µH. A standard 100µH inductor was used in the application circuit. If core loss is a problem, increasing the inductance of L_B will help.

INVERTER TRANSFORMER (T1)

The inverter transformer T1 also has a dual role. Besides stepping up the low voltage to a higher value suitable for the operation of the lamp(s), it is also part of the resonant circuit. The magnetizing inductance of this transformer is the resonating inductor. This transformer is an off the shelf part available from different coil manufacturers. The inverter transformer used in the example circuit is capable of driving one 2W lamp with a start voltage of 1.5KV.

RESONATING CAPACITOR (C6 FOR ML4874, C12 FOR ML4876)

Typically, the value of this capacitor falls between 0.047µF to 0.22µF, depending on the frequency and power level. It should be a low tolerance (±5% typical) low loss type component. A polypropylene or equivalent type capacitor should perform quite well. Some polyester film types may also be suitable for this application.

When used with the above-mentioned inverter transformer with the two lamps at full brightness, a 0.1µF capacitor yields an approximate operating frequency of 48kHz.

CURRENT LIMIT CIRCUIT OF THE BUCK CONVERTER

The buck regulator current control circuit utilizes peak current sense for shutting down the FET instantaneously under over current conditions. The sense resistor is comprised of several resistors in parallel to obtain the desired value.

DIMMING OF THE CCFL LAMPS

Dimming is accomplished by summing a DC current to the inverting input of the error amplifier (pin 7). When a voltage is available instead of current then a resistor can be used.

Figure 8 shows such an arrangement. The 1.6MΩ resistor connected to pin 7 that goes to brightness adjust control serves this purpose. There are several ways of generating the "Brightness Adjust" voltage. The simplest method is by using a potentiometer as shown in Figure 9.

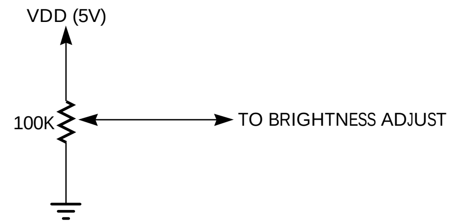


Figure 9. Dimming Voltage Generation.

In the event that the control signal is a PWM modulated digital signal, the circuit shown below may be used.

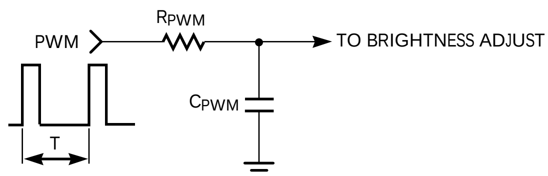


Figure 10. Dimming Voltage Generation using a PWM Signal.

If the PWM signal frequency is high compared to the bandwidth of the control loop, then it is possible to use the circuit of Figure 10 without the added R_{PWM} and C_{PWM}.

For proper operation, however, the following criterion must be met:

$$C_{PWM} \geq \frac{3T}{R_{PWM}} \quad (12)$$

Another method that can be used for dimming is by using a digital up down counter. In this method two push button type switches are used to selectively route the clock pulse either to "UP count" port or the "DOWN count" port. On initial turn-on the circuit requests full brightness. This can be changed by tying pins 12, 13, 19 and 20 of the counter chip to ground. In this condition the circuit will request a full dim condition. Resistors R_A, R_B, R_C and R_D are chosen to provide the required current to the brightness control input. These resistors are chosen to have the 8:4:2:1 ratio for approximately 16 levels of brightness control. For a higher control resolution, an eight bit counter can be used.

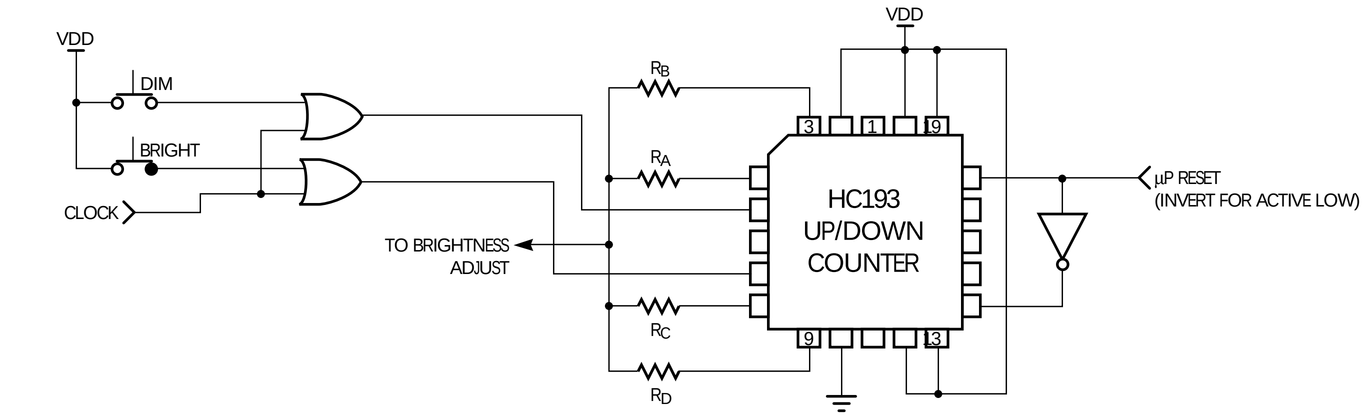


Figure 11. Dimming Voltage Generation using a Digital UP/DOWN Counter.

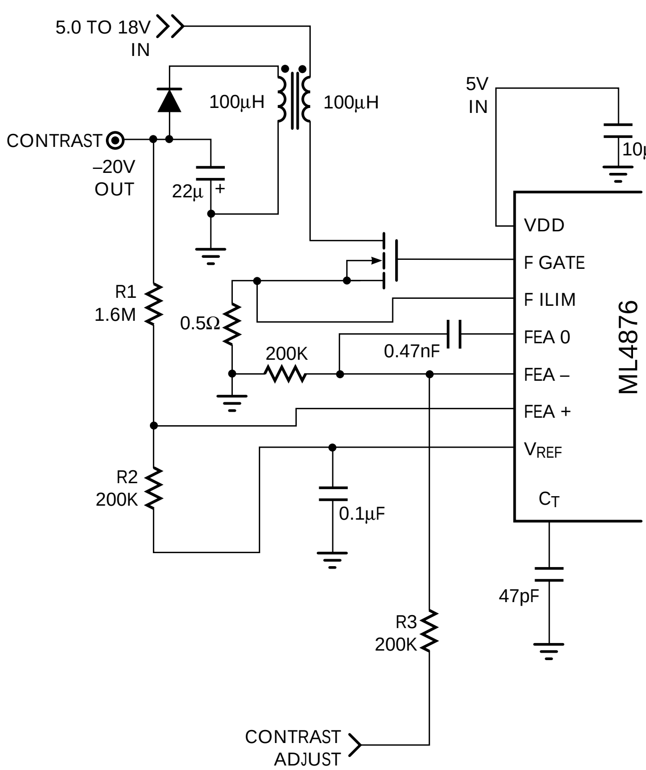


Figure 12. Negative Contrast Voltage Generator Circuit for ML4876 only.

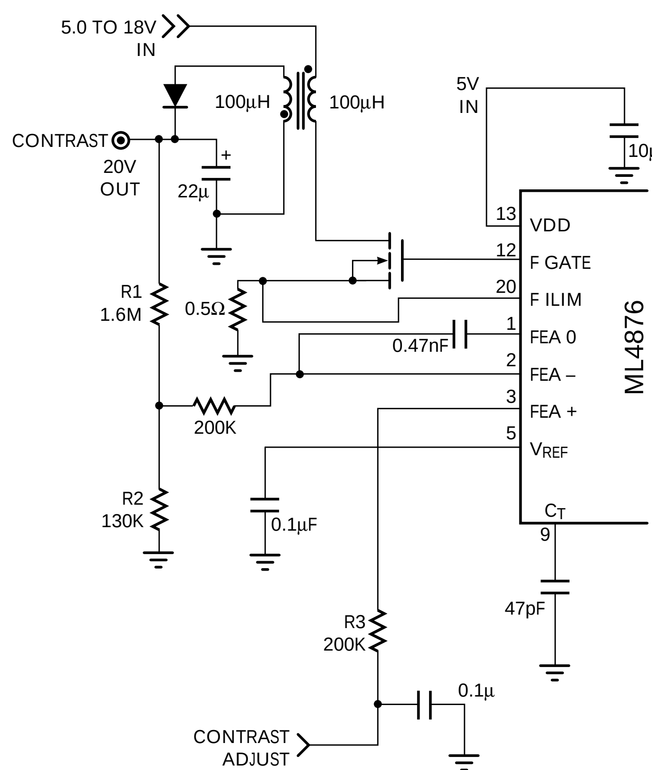


Figure 13. Positive Contrast Voltage Generator Circuit for ML4876 only.

CONTRAST VOLTAGE GENERATOR SECTION (ML4876 ONLY)

The ML4876 contains the necessary control circuitry to implement a positive or negative voltage for the LCD contrast control function. This controller is synchronized to the master clock of the circuit.

To generate a negative voltage the regulator can be configured as a flyback regulator. Figure 12, shows the negative contrast voltage control regulator configuration.

The output voltage of the regulator can be calculated by the following formula:

$$V_{OUT} = -V_{REF}\frac{R_1}{R_2} + \left(1 + \frac{R_1}{R_2}\right)V- \qquad (13)$$

Where: V_{REF} = 2.5V, V_{OUT} is the negative contrast output voltage and V– is the voltage at the inverting pin of the error amplifier (pin 6).

When V– = 0V the output voltage can be calculated:

$$V_{OUT} = -V_{REF}\frac{R_1}{R_2} \qquad (14a)$$

Example: R_1 = 1.6M, R_2 = 200K

$$V_{OUT} = -2.5\frac{1.6M}{200k} = 20V \qquad (14b)$$

To generate a positive contrast control voltage the regulator can be configured as shown in Figure 13.

The output voltage of the regulator can be calculated by the following formula:

$$V_{OUT} = V_{REF}\left(1 + \frac{R_1}{R_2}\right) \qquad (15)$$

SELECTION OF THE FLYBACK TRANSFORMER

The flyback transformer used in this application is an off the shelf item manufactured by various manufacturers. Depending on the output current other parts can be selected for optimum efficiency.

If the range of contrast control voltage is not very wide, the positive contrast voltage can be obtained from the boost configuration directly, thus eliminating one of the windings from Figure 13. If the contrast control voltage is required to adjust to zero, then the additional winding must be used.

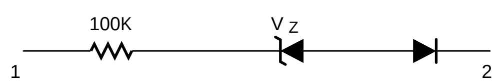
LAMP OUT DETECT

When there is no lamp in the socket, the output voltage will tend to rise to a high level anticipating the start of an actual lamp. This condition is detected by a resistor (R_6 for ML4874, R_8 for ML4876) which is connected to L RTD (pin 10). When the voltage rises above 16 volts at pin 10, the controller will shut down.

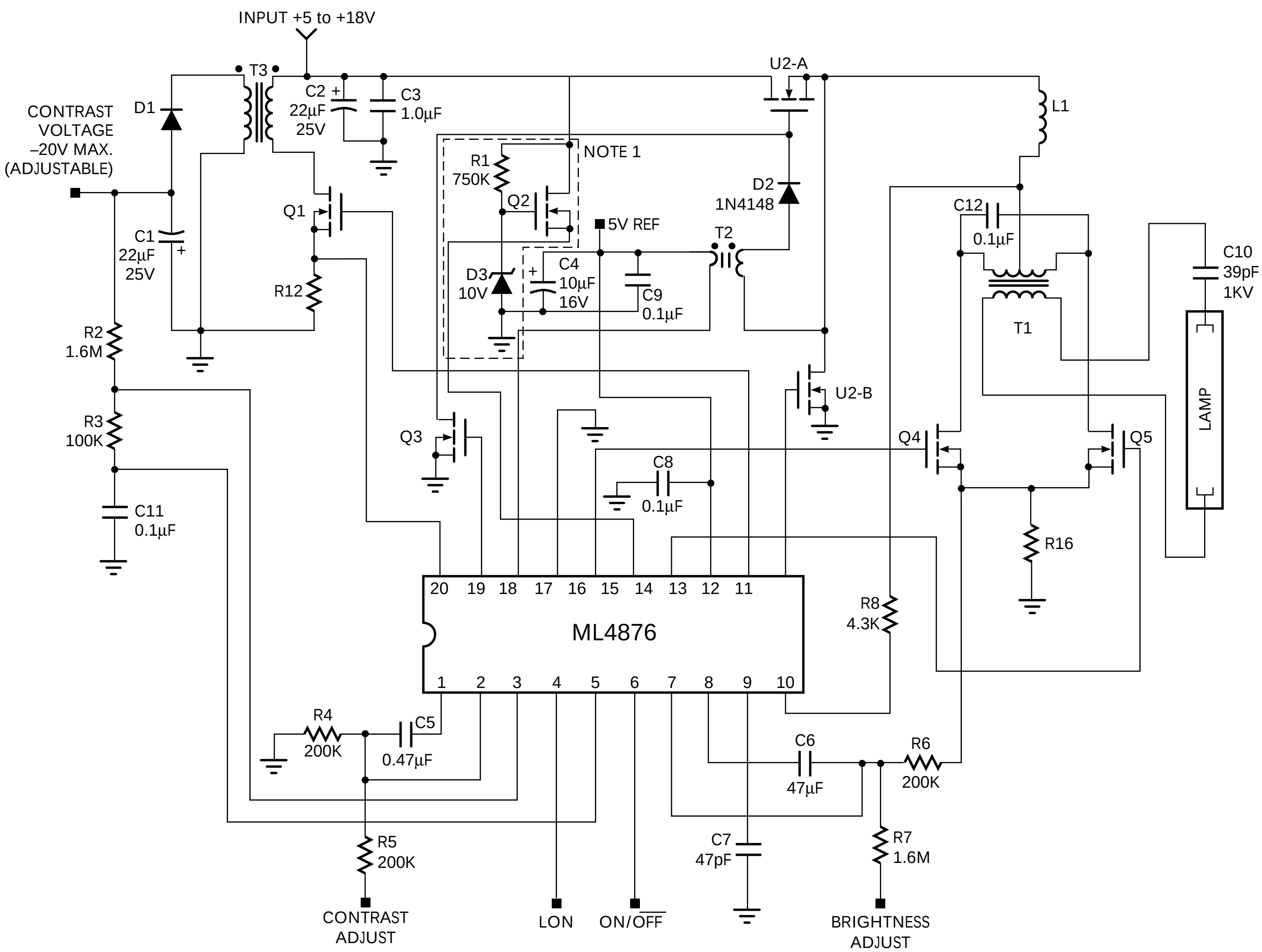
To accommodate different lamp types, sometimes it is desirable to have a voltage higher than 16 volts at the center-tap of the transformer. In this event, another resistor (R17, not shown) can be added between pin 10 and ground to form a voltage divider. The resultant voltage at pin 10 (L RTD) will be:

$$V_{PIN\,10} = V_{CENTER-TAP}\frac{R_{17}}{R_{17} + R_8} \qquad (16)$$

For applications that do not favor the shutting down of the controller, the output voltage can be limited by installing the following circuit, with terminal 1 connected to the center-tap of the transformer and terminal 2 connected to the junction of R_6 and R_7 (see Figure 14): ML4876 only.



When the voltage exceeds the designed value, the zener will breakdown and provide an additional feedback signal to lower the gain of the controller, thus limiting the output voltage.



NOTE 1
R1, D3, Q2 ARE OPTIONAL AND ALLOWS A BATTERY VOLTAGE RANGE FROM +7 TO +28V. REMOVING THESE COMPONENTS AND CONNECTING DIRECTLY TO THE INPUT VOLTAGE ALLOWS +5.0 TO +18V.

Figure 14. Application Schematic for the ML4876.

PARTS LIST OF A TYPICAL ML4874 BACKLIGHT CIRCUIT

All parts are SMD unless otherwise noted.

QTY.	DESCRIPTION	VENDOR/ PARTS	REV./ ISSUE
Resistors (All resistors are 1/4 watt)			
2	1.6M 5%	1206	R1, R4
1	82K 5%	1206	R2
1	100K Ohm 5%	1206	R3
2	1.0 Ohm 5%, 2 in parallel	1206	R5 (X2)
1	4.3K 5%	1206	R6
Capacitors			
1	33µF 6.3VDC Tantalum	Nichicon (F930J3366MC)	C1
1	22µF 25VDC Tantalum	Nichicon (F931D226MN)	C7
5	0.1µF 50VDC	1206	C2, C3, C8, C9
1	47pF 50VDC	0603	C5
1	0.1µF 63VDC Polyester	WIMA MKS-2 (or equal) leaded	C6
1	0.047µF 50VDC	0805	C4
1	39pF 1KV	leaded	C11
1	1µF/50V	1206	C10

QTY.	DESCRIPTION	VENDOR/ PARTS	REV./ ISSUE
Semiconductors			
1	1N4148	RLS4148-LL34	D1
2	2N7002	SOT-23	Q1, Q2
1	MMFD2N02E	SO 08 Dual FET	U2
1	MMFT3055ELT1	MOSFET SOT-223	Q3, Q4
Magnetics			
1	EPS136 #6345-020 or CTX210655-1	Sumida Coiltronics	T1
1	CP-4LBM 5201-JPS-021	Sumida	T2
1	CTX100-4 or CDR105	Coiltronics Sumida	L1
Lamp			
1	LFOM2476	Sharp	
Hardware			
6	Header pins 0.025 sq. posts		

PARTS LIST OF A TYPICAL ML4876 BACKLIGHT CIRCUIT

All parts are SMD unless otherwise noted.

QTY.	DESCRIPTION	VENDOR/ PARTS	REV./ ISSUE
Resistors (All resistors are 1206 unless otherwise noted)			
2	1.6M		R1, R2
1	200K		R3
2	200K		R4, R5
1	4.3K		R8
6	1.0 Ohm (resistors in parallel)		R9, R10, R11, R12 R13, R14, (R15, R16 Optional)
1	200K	0805	R6
1	1.6M	0805	R7
The following are on the break-off board			
2	10K Carbon, 10%, Leaded		R/PU (X2)
1	User selectable, Leaded		R Load
2	20K (Bourns 3352 Series, or similar)		R-POT (X2)
Capacitors			
2	22µF/25VDC Tantalum	Nichicon (F91E226MN)	C1, C2
1	1.0µF/50VDC	1206	C3
1	10µF/16VDC Tantalum	Nichicon (F931C106MB)	C4
2	0.047µF/50VDC	0805	C5, C6
1	47pF/50VDC	0603	C7
3	0.1µF/50VDC	1206	C8, C9, C11
1	39pF/1KV Ceramic Disk	Leaded	C10
1	0.1µF/63VDC	Leaded (WIMA MKS2)	C12

QTY.	DESCRIPTION	VENDOR/ PARTS	REV./ ISSUE
Diodes			
2	1N4148	RLS4148-LL34	D1, D2
1	Zener 10V	LL34	D3
Transistors			
2	2N7002	SOT-23	Q2, Q3
3	MMFT3055ELT1	MOSFET SOT-223	Q1, Q4 Q5
1	MMFD2N02E	Dual FET S008	U2
Magnetics			
2	CTX100-1 or CDR105	Coiltronics Sumida	L1, T3
1	EPS136 #6345-020 or CTX210655-1	Sumida Coiltronics	T1
1	CP-4LBM 5201-JPS-021 or Ferrite Bead 1Turn:2 Turns	Sumida	T2