Contents

1. AP2001 Specifications

1.1 Features

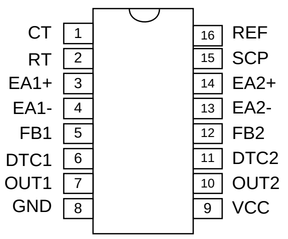
- Dual PWM Control Circuitry
- Operating Voltage can be up to 50V
- Adjustable Dead Time Control (DTC)
- Under Voltage Lockout (UVLO) Protection
- Short Circuit Protection (SCP)
- Variable Oscillator Frequency...... 500KHz Max
- 2.5V Voltage Reference Output
- 16-pin PDIP and SOP Packages

1.2 General Description

The AP2001 integrates Pulse-width-Modulation (PWM) control circuit into a single chip, mainly designs for power-supply regulator. All the functions include an on-chip 2.5V Reference Output, two Error Amplifiers, an Adjustable Oscillator, two Dead-Time Comparators, UVLO, SCP, DTC circuitry, and Dual Common-Emitter (CE) output transistor circuits. Recommend the output CE transistors as pre-driver for driving externally. The DTC can provide from 0% to 100%. Switching frequency can be adjustable by trimming RT and CT. During low VCC situation, the UVLO makes sure that the outputs are off until the internal circuit is operating normally.

1.3 Pin Assignments

(Top View)

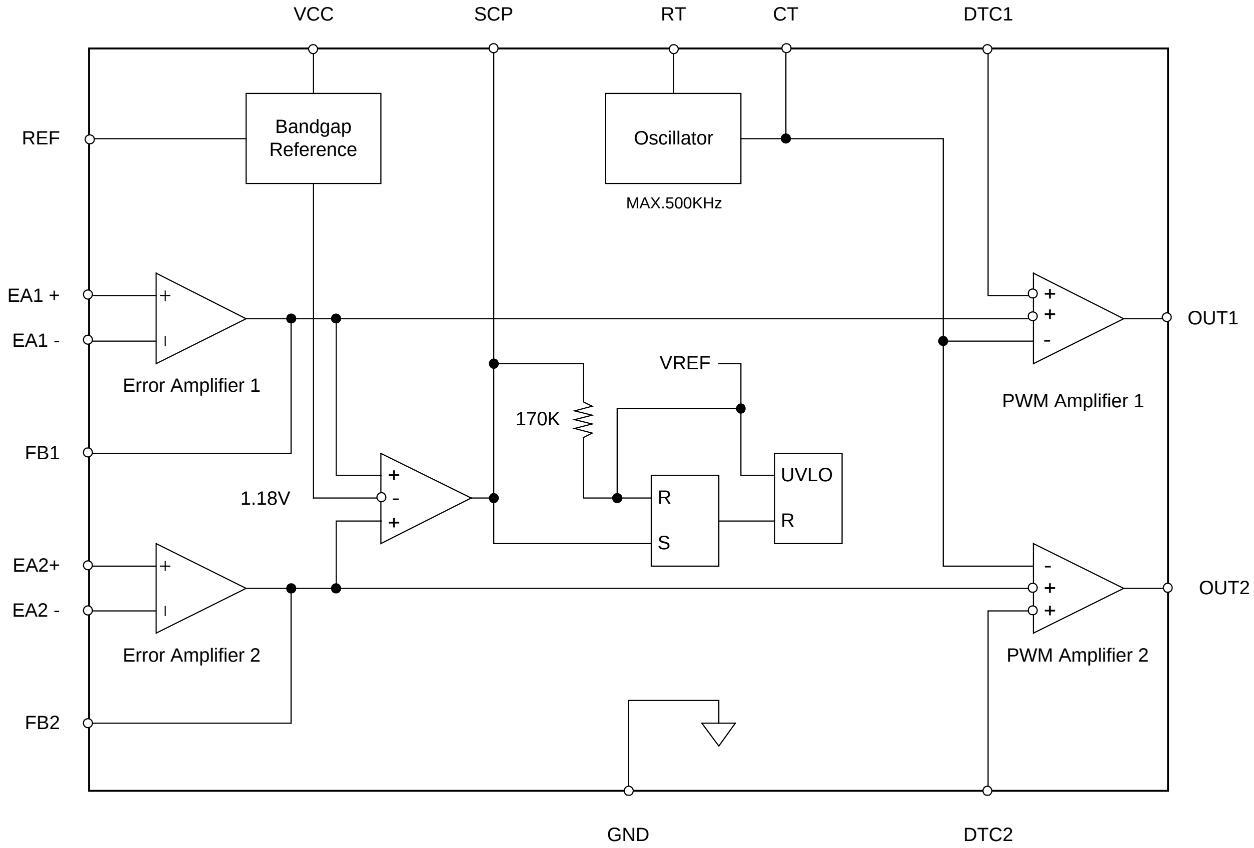


PDIP/SOP

1.4 Pin Descriptions

Name	Description
CT	Timing Capacitor
RT	Timing Resistor
EA+	Error Amplifier Input(+)
EA -	Error Amplifier Input(-)
FB	Feedback Loop Compensation
DTC	Dead Time Control
OUT	Pre-driver Output
GND	Ground
VCC	Supply Voltage
SCP	Short Circuit Protection
REF	Voltage Reference

1.5 Block Diagram



1.6 Absolute Maximum Ratings

Symbol	Parameter	Rating	Unit
V_{CC}	Supply Voltage	40	V
V_I	Amplifier Input Voltage	20	V
V_O	Collector Output Voltage	40	V
Io	Collector Output Current	21	mA
T_{OP}	Operating Temperature Range	-20 to +85	^oC
T_{ST}	Storage Temperature Range	-65 to +150	^oC
T_{LEAD}	Lead Temperature 1.6 mm (1/16 inch) from Case for 10 Seconds	260	^oC

2. Hardware

2.1 Introduction

The CCFL presents a highly nonlinear load to the converter. Initially when the lamp is cold (inoperative for some finite time), the voltage to fire the lamp is typically more than three times higher than the sustaining voltage. The lamp characteristic fires at 1800V and exhibits an average sustaining voltage (Vn) of 600V. Notice that the lamp initially exhibits a positive resistance and then transitions to a negative resistance above 1mA. These characteristics dictate a high output impedance (current source) drive to suppress the negative load resistance effect and limit current during initial lamp firing. Since the ZVS (zero voltage switched) converter has low output impedance, an additional “lossless” series impedance such as a coupling capacitor must be added. To facilitate analysis, the equivalent CCFL circuit (shown in figure 1) is used. VFL is the average lamp sustaining voltage over the operating range. The lamp impedance (RFL) is a complex function, but can be considered a fixed negative resistance at the sustaining voltage. Stray lamp and interconnect capacitance are lumped together as CCFL.

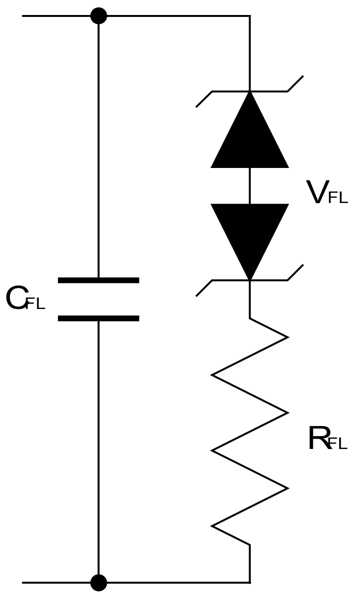


Figure 1. CCFL equivalent circuit

The CCFL inverter demo board supply 2~4 pcs lamp. This board can supply output power up to 8.4W for every transformer output (600Vrms / 14mA). Using a dc input voltage of 10.8 V to 13.2 V, The control method used in the board is fixed frequency, variable on-time pulse-width-modulation (PWM). The feedback method used is voltage-mode control. Other features of the board include under voltage lockout (UVLO), short-circuit protection (SCP), and adjustable dead time control (DTC).

2.2 Description of the CCFL inverter circuit

The CCFL inverter circuit is comprised of the current regulating buck converter and the Royer-type resonant oscillator. The buck converter controls the magnitude of CCFL current. This feature is instrumental in providing dimming control. The Royer-type resonant oscillator circuit is shown in Figure 2.

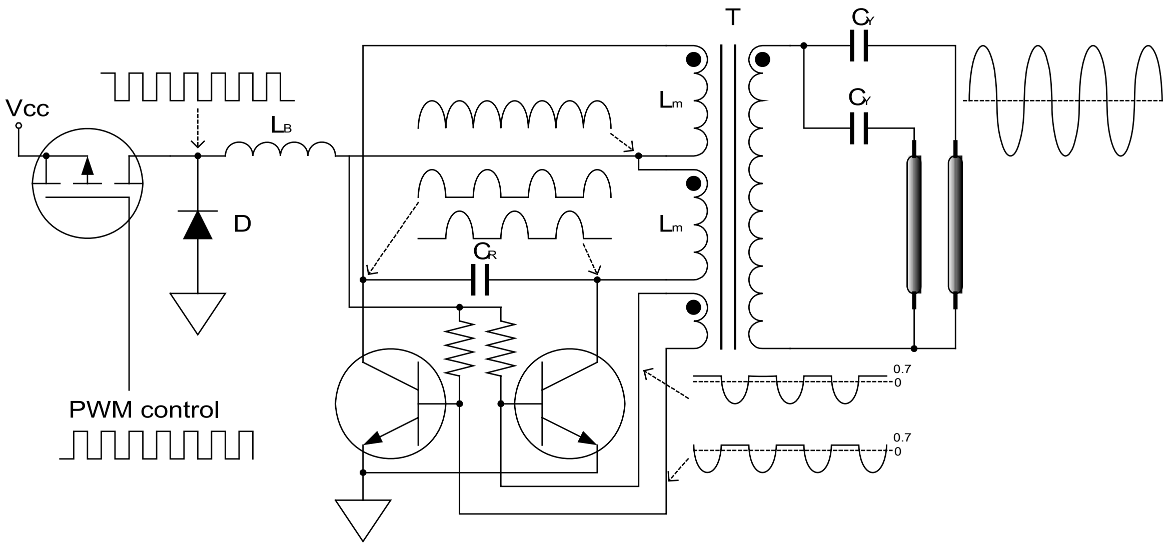


Figure 2. Royer-type Resonant Oscillator Circuit

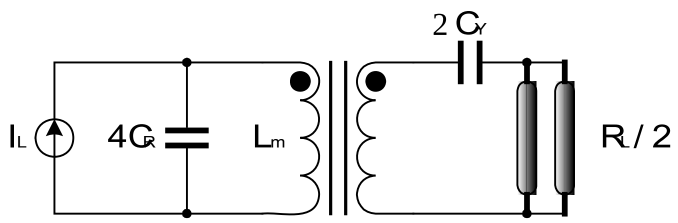


Figure 3. Simplified Royer-type Resonant Oscillator Circuit

- Royer-type Resonant Oscillator

The circuit shown in Figure 2 is essentially a current fed parallel loaded parallel resonant circuit, which can be further simplified to that shown in Figure 3. The simplification in Figure 3 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. 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 AP2001 is set lower than the resonant frequency to ensure synchronization. The current source labeled IC in Figure 2 is a conceptual current-fed which models the function of L_B.

- Buck Converter

The Buck converter converts a DC voltage to a lower DC voltage. *Figure 4* shows the basic buck topology. When the switch SW is turned on, energy is stored in the inductor L and it has constant voltage “$V_L = V_i - V_o$”, the inductor current *iL* ramps up at a slope determined by the input voltage. Diode D is off during this period. Once the switch, SW, turns off, diode D starts to conduct and the energy stored in the inductor is released to the load. Current in the inductor ramps down at a slope determined by the difference between the input and output voltages.

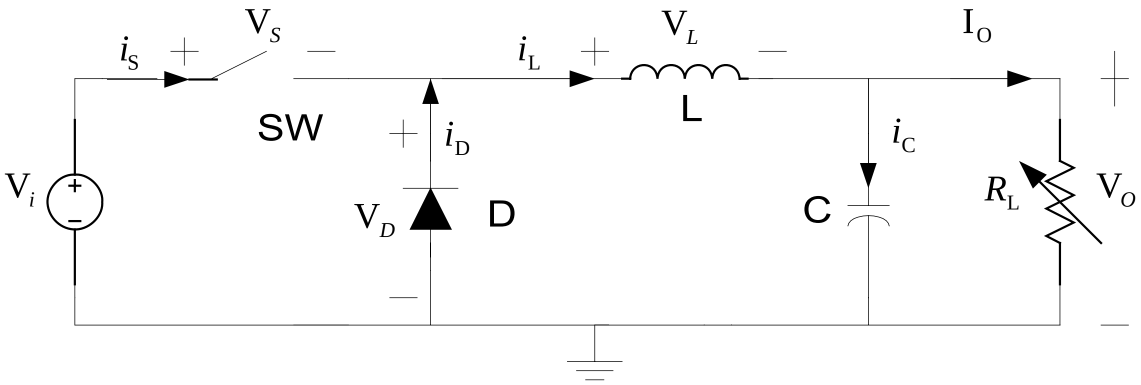


Figure 4. Typical Buck Converter Topology

2.3 Input / Output Connections

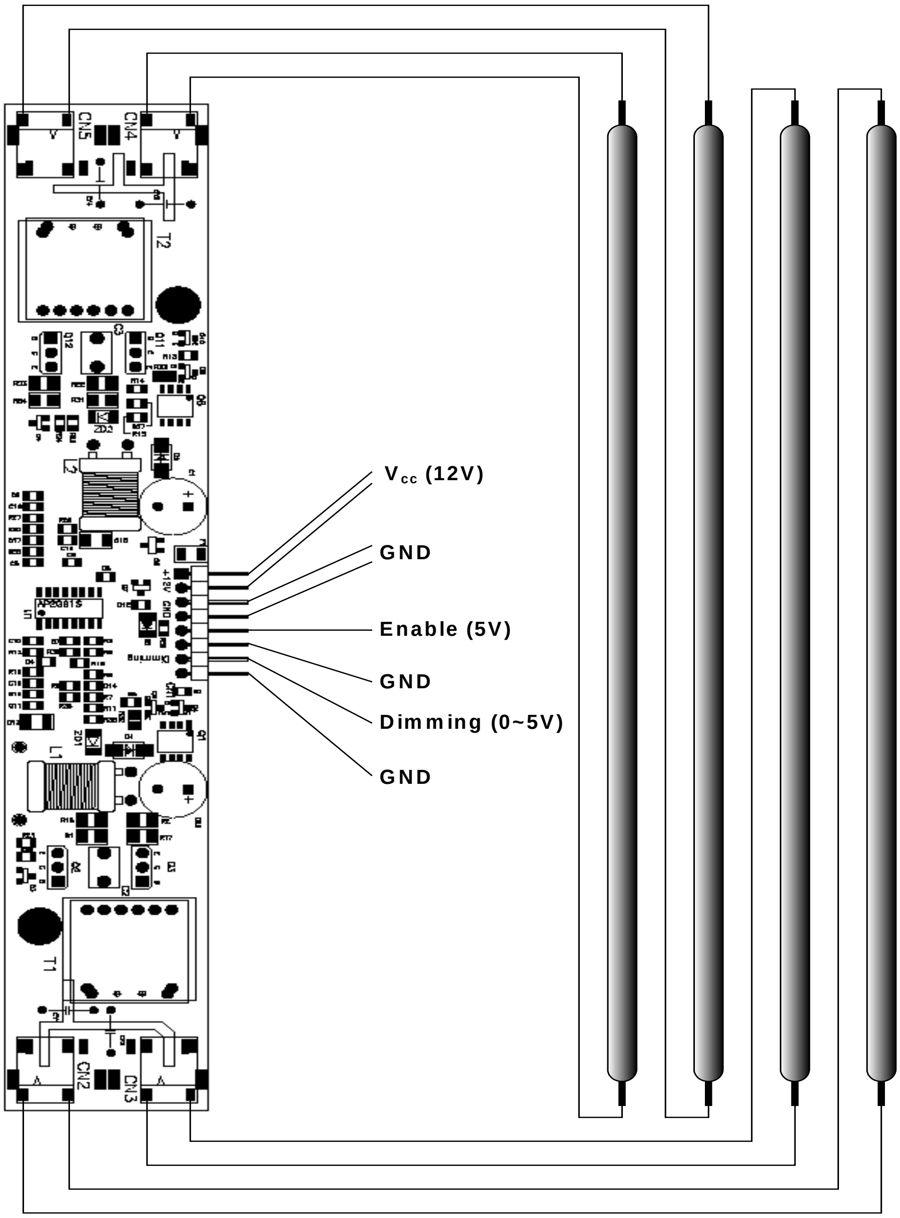


Figure 5. I/O Connections

2.4 Schematic

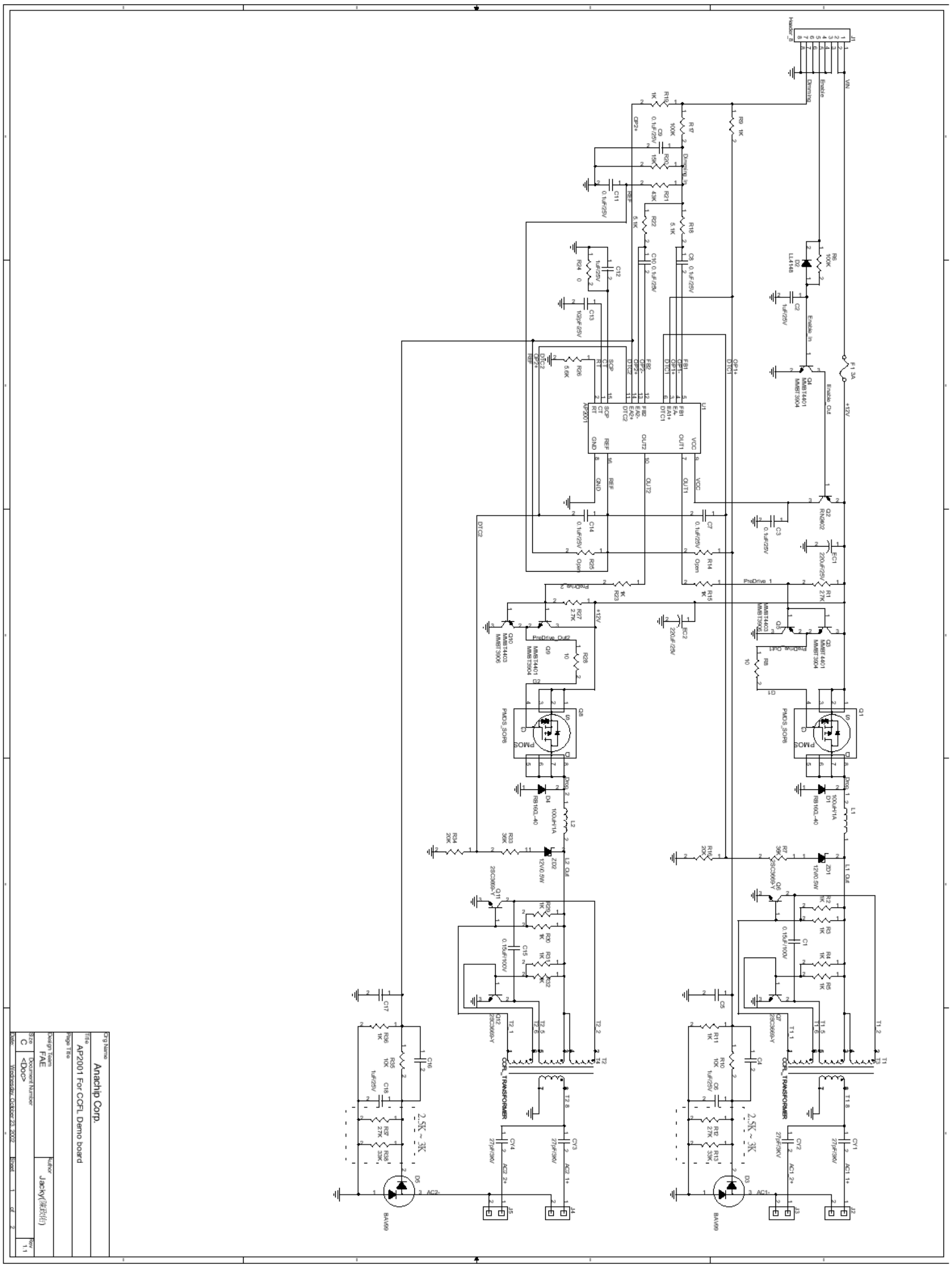


Figure 6. CCFL Inverter Schematic

2.4 Board of Materials

No.	Value	Q'ty	Part Reference	Description	Manufacturers	Part Number
1	0.15uF/100V	2	C1 C15	Metallized Polyester Film CAP. 0.15uF 100V	ARCOTRONICS EPCOS	
2	1uF/25V	2	C2 C12	Ceramic Chip CAP. 1uF 25V ±10% K X7R 0805	Philips, Team-Young	
3	0.1uF/25V	7	C3 C7 C8 C9 C10 C11 C14	Ceramic Chip CAP. 0.1uF 25V ±10% K X7R 0805	Philips, Team-Young	
4	Open	4	C4 C5 C16 C17	To be Defined		
5	1uF/25V	2	C6 C18	Ceramic Chip CAP. 1uF 50V ±10% K X7R 1206	Philips, Team-Young	
6	102pF/25V	1	C13	Ceramic Chip CAP. 102pF 50V ±10% K X7R 0805	Philips, Team-Young	
7	27pF/3KV	4	CY1 CY2 CY3 CY4	Ceramic CAP.SL (NPO) 27pF ± 5% 3KV	TDK, MURATA	
8	RB160L-40	2	D1 D4	Schottky Diode 1A 40V	DIODES ROHM	B140 RB160L-40
9	LL4148	1	D2	Switching Diode 0.15A 75V	ROHM DIODES	LL4148 LL4148
10	BAV99	2	D3 D5	Dual Switching Diode 0.15A 75V	ROHM DIODES	BAV99 BAV99
11	220uF/25V	4	EC1 EC2 EC3 EC4	Electrolysis CAP. 220uF 25V	NIPPON, NICHICON	
12	3A	1	F1	Fuse F/P 3A 32V 1206	LITTLEFUSE	429003
13	Header_8	1	J1	2.54mm Connectors 90° 8 Pin Header Single Row	E & T	
14	CON2	4	J2 J3 J4 J5	3.5mm Disconnectable Crimp Style Connectors	JST	SM02B
15	CON2	1	J6	5.08mm PCB Terminal Block 2 Pin	DINKLE	ELK508V-02P
16	Power_Jack	1	J7	DC Power Jack 6.4mm/2.5mm	LIH SHENG	
17	Header_8	1	J8	2.54mm Connectors 90° 8pin Female Header Single Row	E & T	
18	100uH/1A	2	L1 L2	Choke Coil 100uH 1A	Delta	86A-2094
19	LED	1	LED1	Through-Hole Green 5mm(Pitch 2.54mm)	KingBright	L1513GT
20	PMOS_SOP8	2	Q1 Q8	P-Channel MOSFET -30V -5A	Toshiba Fairchild	TPC8104-H FDS9435
21	RN2402	1	Q2	Built-in Resistance PNP BJT -50V -0.1A SC-59	Toshiba ROHM	RN2402 DTA114EK
22	MMBT4401	3	Q3 Q4 Q9	NPN BJT 40V 0.6A SOT-23	ROHM DIODES	SST2222A MMBT4401
23	MMBT4403	2	Q5 Q10	PNP BJT -40V -0.6A SOT-23	ROHM DIODES	SST2907A MMBT4403
24	2SC3669-Y	4	Q6 Q7 Q11 Q12	NPN BJT 80V 2A	Toshiba	2SC3669-Y
25	2.7K	4	R1 R12 R27 R37	Chip Resistance 2.7K 1/8W ±10% J 0805	Yageo(RL Series)	
26	1K	8	R2 R3 R4 R5 R29 R30 R31 R32	Chip Resistance 1K 1/4W ±10% J 1206	Yageo(RL Series)	
27	100K	2	R6 R17	Chip Resistance 100K 1/8W ±10% J 0805	Yageo(RL Series)	
28	36K	2	R7 R33	Chip Resistance 36K 1/8W ±10% J 0805	Yageo(RL Series)	
29	10	2	R8 R28	Chip Resistance 10 1/8W ±10% J 0805	Yageo(RL Series)	

No.	Value	Q'ty	Part Reference	Description	Manufacturers	Part Number
30	1K	4	R9 R11 R15 R19 R23 R36	Chip Resistance 1K 1/8W ±10% J0805	Yageo(RL Series)	
31	9.1K	2	R10 R35	Chip Resistance 9.1K 1/8W ±10% J 0805	Yageo(RL Series)	
32	33K	2	R13 R38	Chip Resistance 33K 1/8W ±10% J 0805	Yageo(RL Series)	
33	Open	2	R14 R25	To be Defined		
34	20K	2	R16 R34	Chip Resistance 20K 1/8W ±10% J 0805	Yageo(RL Series)	
35	5.1K	3	R18 R22	Chip Resistance 5.1K 1/8W ±10% J 0805	Yageo(RL Series)	
36	15K	1	R20	Chip Resistance 15K 1/8W ±10% J 0805	Yageo(RL Series)	
37	43K	1	R21	Chip Resistance 43K 1/8W ±10% J 0805	Yageo(RL Series)	
38	0	2	R24 R42 R43	Chip Resistance 0 1/8W ±10% J 0805	Yageo(RL Series)	
39	5.6K	1	R26	Chip Resistance 5.6K 1/8W ±10% J 0805	Yageo(RL Series)	
40	120	1	R39	Chip Resistance 120 1/8W ±10% J 0805	Yageo(RL Series)	
41	360	1	R40	Chip Resistance 362 1/8W ±10% J 0805	Yageo(RL Series)	
42	470	1	R41	Chip Resistance 470 1/8W ±10% J 0805	Yageo(RL Series)	
43	SW_SPDT	1	SW1	SPDT Switch 3pin		
44	CCFL Transformer	2	T1 T2	Inverter X'FMR (10/10/3):1500TS	Delta	INT018T
45	AP2001	1	U1	Monolithic Dual Channel PWM Controller	Anachip	AP2001S
46	AP1117	1	U2	1A Positive Low Dropout Regulator	Anachip	AP1117T50
47	10K	1	VR1	Variable Resistance 10K		
48	12V/0.5W	2	ZD1 ZD2	Zener Diode 0.5W 12V	ROHM DIODES	RLZ TE-11 12C ZMM5242B

2.6 Board Layout

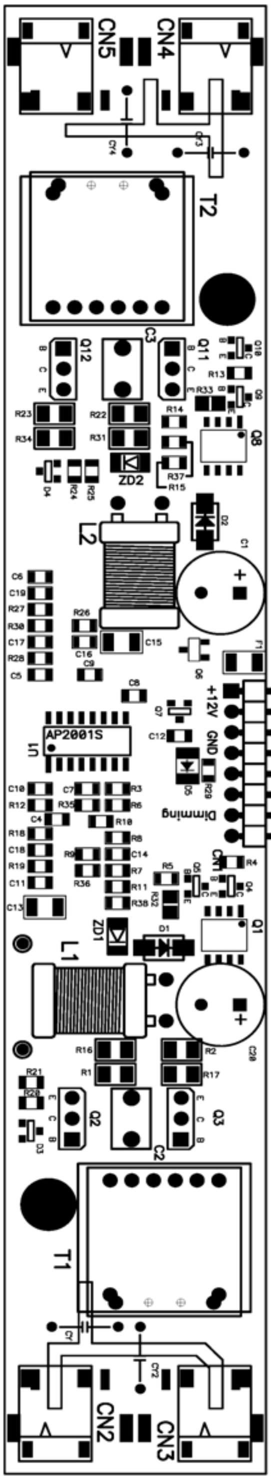


Figure 8. Top silk layer

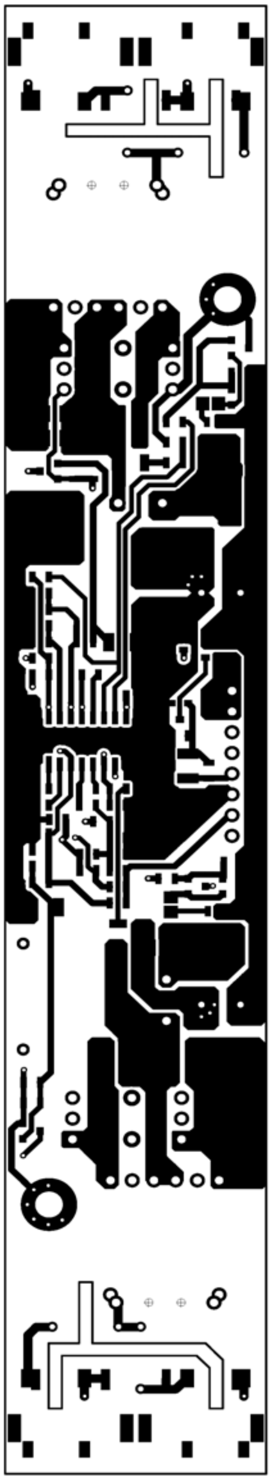


Figure 9. Top layer

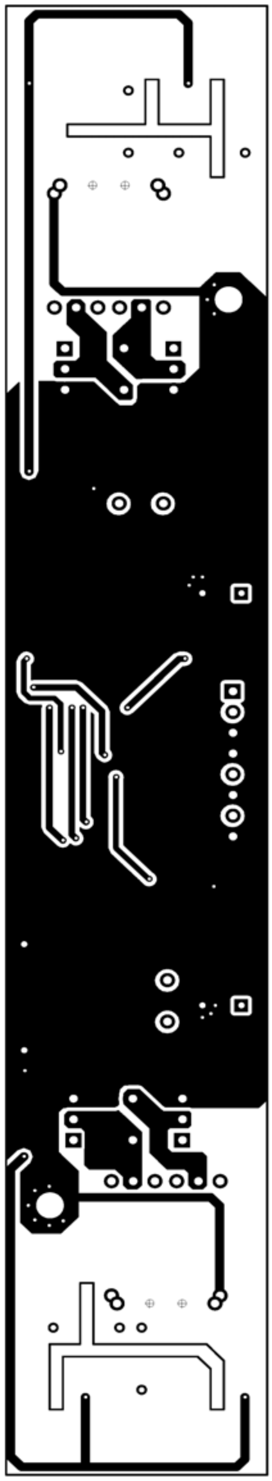


Figure 10. Bottom layer

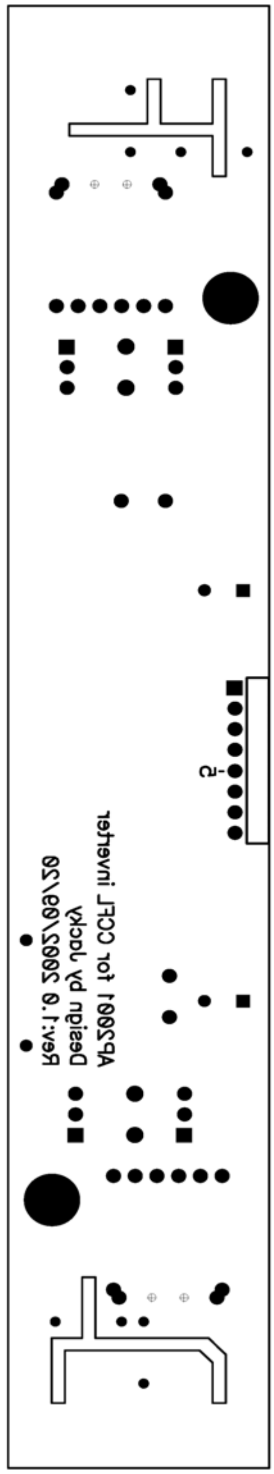


Figure 11. Bottom Silk layer

3. Design Procedure

3.1 Introduction

The AP2001 integrated circuit is a dual PWM controller. It operates over a wide input voltage range. Being low in cost, it is a very popular choice of PWM controller. This section will describe the AP2001 design procedure. The operation and the design of the CCFL inverter will also be discussed in detail.

3.2 Operating Specifications

Specification	Min	Typ	Max	Units
Input Voltage	10.8	12	13.2	V
Operating Frequency	90	100	110	KHz
Output Frequency	40	50	60	KHz
Output Power (For every Transformer)	0	Dimming	8.4	W
Output Voltage (No Load)		1500	1800	Vrms

Table 1. Operating Specifications

3.3 Design Procedures

This section describes the steps to design current regulating buck converters and Royer-type oscillators, and explains how to construct basic power conversion circuits including the design of the control chip functions and the basic loop. A switching frequency of 100 kHz was chosen.

3.3.1 Current Regulating Buck Converter

Example calculations accompany the design equations. Since this is a fixed output inverter, all example calculations apply to the converter with an output power of 8.4W and input voltage set to 13.2V, unless specified otherwise. The first quantity to be determined is the converter of the duty cycle value.

$$\text{Duty ratio } D = \frac{V_o + V_d}{V_{in} - V_{ds(sat)}} = \frac{T_{on}}{T_s} \quad , \quad 0 \leqq D \leqq 1$$

Assuming the commutating diode forward voltage Vd = 0.5 V, the power switch on voltage $V_{ds(sat)}$ = 0.1V and Vo = $V_{PRI(DC)}$ is dependent on CCFL (1 or 2 lamp, required current). In this case $V_{PRI(DC)}$ = 10.8V and Io = 0.78A for one lamp, $V_{PRI(DC)}$ = 7.5V, Io = 1.12A and for two lamp, so the duty cycle for V_{in} = 13.2 is 0.78 for one lamp and 0.61 for two lamps. 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. Choose an inductor to maintain continuous-mode operation down to 20 percent ($I_{o(min)}$) of the rated output load:

$$\Delta I_L = 2 \times 20\% \times I_o = 2 \times 0.2 \times 0.78 = 0.31A$$

The inductor "L_B" value for one lamp is connected to be:

$$L_B \geqq \frac{(V_{in} - V_{ds(sat)} - V_o) \times D_{min}}{\Delta I_L \times f_s} = \frac{(13.2 - 0.1 - 10.8) \times 0.78}{0.31 \times (100 \times 10^3)} = 58\mu H$$

If the transformer's output connects two lamps then $L_B \geqq 76\mu H$ on above, so we choose buck inductor value to be 100uH for this case. If core loss is a problem, increasing the inductance of L will help. Other component selection (PMOS, Diode, C_{out}), please refer the AP2001 for Buck+Boost demo board manual.

3.3.2 Royer-type Resonant Oscillator

The current fed Royer-type converter shown in figure 3 is driven at its resonant frequency to provide ZVS operation. The BJTs (Q1 & Q2) are alternately driven at 50% duty cycle. Commutation occurs as V1 and V2 resonate through zero thereby insuring zero voltage switching. This virtually eliminates switching losses associated with charging BJT output and stray capacitance, and reduces base drive losses by minimizing the base charge. Current is supplied to the Royer-type stage by a buck regulator (Q3). Winding inductance, L_R, and C_R, the combined effective capacitance of C_R and the reflected secondary capacitances make up the resonant tank. The secondary side of the transformer exhibits a symmetrical sine wave voltage varying from about 300Vrms to 1800Vrms. Capacitor C_Y provides ballasting and insures that the converter is only subjected to positive impedance loads. Example calculations accompany the design equations. All example calculations apply to the converter with output striking voltages of 1500V_{rms}, operating voltages of 600V_{rms} and input voltages set to 12V, unless specified otherwise.

3.3.2.1 Selection of the Transformer (T)

The inverter transformer T1 also has triple roles. Besides stepping up the low voltage to a higher value suitable for the operation of the lamp(s), it is also a part of the resonant circuit and driver of external BJTs. 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 4.2W lamp with a start voltage of 1800V. The striking voltage is dependent on supply voltage and the turn ratio (TR) of transformer as described below.

$$V_{strike(rms)} \geqq \frac{\pi \times V_{PRI(DC)} \times TR}{2\sqrt{2}}$$

$$TR \geqq \frac{2\sqrt{2} \times V_{strike(rms)}}{\pi \times V_{PRI(DC)}} = \frac{2\sqrt{2} \times 1800}{\pi \times 10.8} = 150$$

So we choose part number "INT018T-1" CCFL transformer of Delta.

In this transformer, L_m = 10uH, TR = 1500/10 = 150, $R_{DC(PRI)}$ = 63mΩ , $R_{DC(SEC)}$ = 602Ω

3.3.2.2 Selection of the Ballast Capacitor (CY)

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:

$$R_L = \frac{V_L}{I_L}$$

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_Y is chosen such that its reactance is approximately equal to the lamp resistance R_L. The two capacitors C_Y are used to simulate two separate current sources, so that the current will be shared between the lamps. The typical value for R_L is 100KΩ. For a typical operating frequency of 50kHz, C_Y yields a capacitor's reactance of approximately 100KΩ. The best choice for this capacitor is from 27 to 33pF. In many practical designs, for minimizing current distortion caused by the non-linear behavior of the lamp, $V_{C(BALLAST)}$ is set to be around 1.2~ 2 times of V_{LAMP}.

$$V_{C(BALLAST)} = \frac{I_{LAMP}}{2\pi \times F_{LAMP} \times C_Y} = K \times V_{LAMP},\ K = 1.2 \sim 2$$

$$C_Y = \frac{I_{LAMP}}{2\pi \times F_{LAMP} \times K \times V_{LAMP}} = \frac{7m}{2\pi \times 50K \times 1.3 \times 600} = 29pF$$

So we choose 27pF/3KV, a smaller C_Y can make more linear the lamp connection.

3.3.2.3 Selection of the Resonant Capacitor (C_R)

The primary and secondary circuits determine the resonant frequency of the Royer oscillator. 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:

$$F_{LAMP} = \frac{1}{2\pi \sqrt{[L_m(4C_R + n \times TR^2 \times C_Y)]}}$$

Where: n is the number of lamps at the output with ballasting capacitors C_Y, TR is the secondary to primary turns ratio of T1, L_m is the primary inductance of T1 and C_R is the capacitance across the primary.

$$50K = \frac{1}{2\pi \sqrt{[10u(4 \times C_R + 1 \times 22500 \times 27p)]}}$$

C_R = 0.101uF
So we choose 0.15uF/100V

3.3.2.4 Selection of the Push-Pull Transistors (Q)

The push-pull output BJTs(Q6, Q7, Q11, Q12) are alternately driven at 50% duty cycle by the transformer (pin1 and pin6). Commutation occurs as $V_{C(Q6)}$ and $V_{C(Q7)}$ resonate through zero thereby insuring zero voltage switching. This virtually eliminates switching losses associated with charging BJT output and stray capacitance, and reduces base drive losses by minimizing the base current. The current of the transformer primary I_{PRI} is:

$$I_{PRI} = \frac{V_{PRI}}{Z_{TANK}}, \qquad Z_{TANK} = \sqrt{\left(\frac{L_m}{C_R}\right)},\ V_{PRI(RMS)} = \frac{V_{SEC(RMS)}}{TR} = \frac{1800}{150} = 12V_{(RMS)}$$

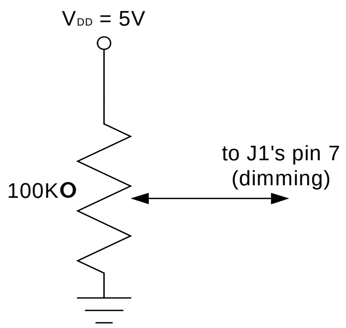
so we can obtain $I_{PRI(MAX)}$ approximately 1.47A and $V_{PRI(PEAK)} = V_{PRI(RMS)}\sqrt{2}$ approximately 17V. Therefore, the BJT's $V_{CEO} = 2 \times V_{PRI(PEAK)}$ = 34V, We can choose 2 ~ 3 times of V_{CEO} and 1.5 ~ 2 times of I_C appropriate BJT, the Toshiba's transistor "2SC3669" is selected by us. It's V_{CEO} = 80V and I_C = 2A.

3.3.2.6 Brightness Adjust of the Lamp

- Brightness adjust

There are several ways of generating the "brightness adjust" voltage. The simplest method is by using a potentiometer as shown in Figure 10. If the 1KΩ resistor installed to R9/R19 that goes to brightness adjust control serves from dark to light, its method of brightness adjustment is modulating OP+(feedback) voltage to change duty cycle of PWM out. If R9/R19 is not installed 1KΩ resistor then brightness adjust control serves from dim to light, its method of brightness adjustment is modulating OP-(compared voltage) voltage to change duty cycle of PWM out.

Figure 12. Dimming voltage generation



- Brightness Fixed

If you would like brightness fixed then just remove R9, R17, R19, and modify R11/R36 resistance value, it is modulating appropriately for feedback (OP+) voltage to fixed duty cycle of PWM out.

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