The Silicon Valley Connection

MN9910-ANDB220

Application Note for the 220V Off-Line High Brightness LED Driver Demo Board

- PRELIMINARY -

INTRODUCTION

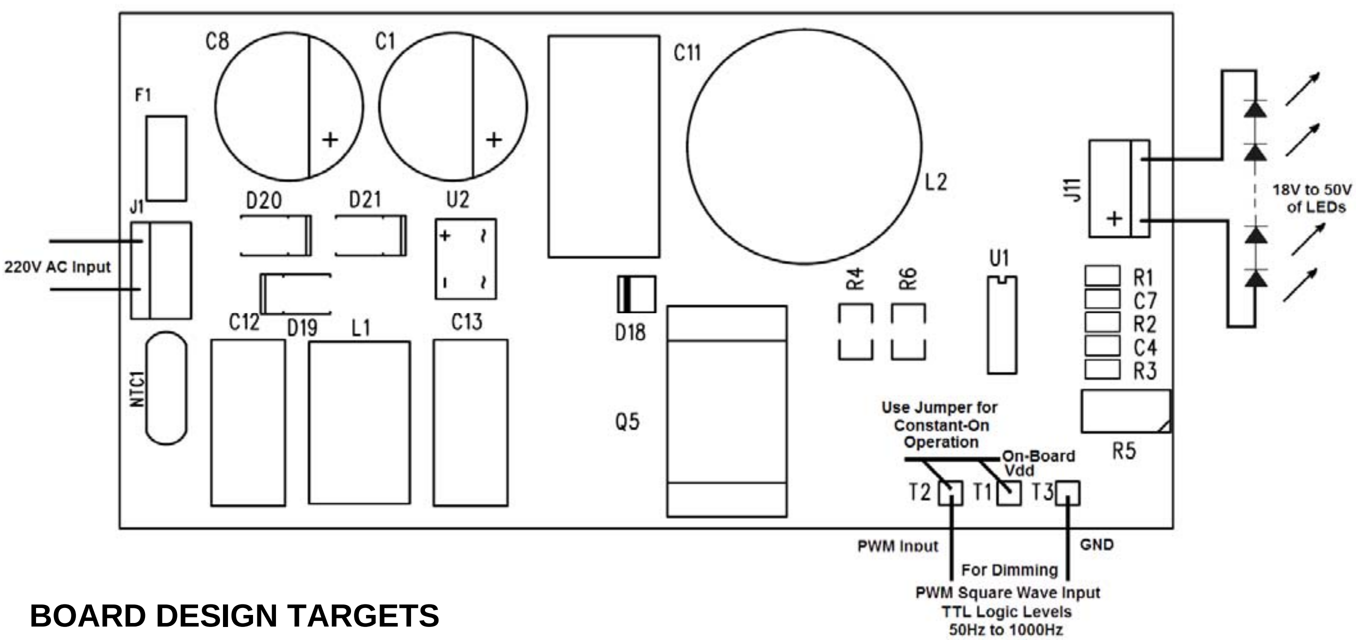
DESCRIPTION

This application note presents the MN9910DB-220V that is the standard MN9910B demo board, configured to exercise high brightness LEDs driven from 220V Mains Supply. Up to 50V of series LEDs can be driven, at currents ranging from 175mA to 750mA, using the on-board trimming potentiometer. With simple ballasting techniques, multiple strings of LEDs can also use the higher current ranges. The on-board oscillator is set at 51 kHz, near the center of the frequency capability, to allow operation off 220Mains, while supporting LED currents as low as 175mA

As for a production design, the LED current setting is fixed with a potentiometer adjustment applied to the linear dimming pin. PWM dimming can then be achieved by applying a pulse-width-modulated square wave to the PWMD pin.

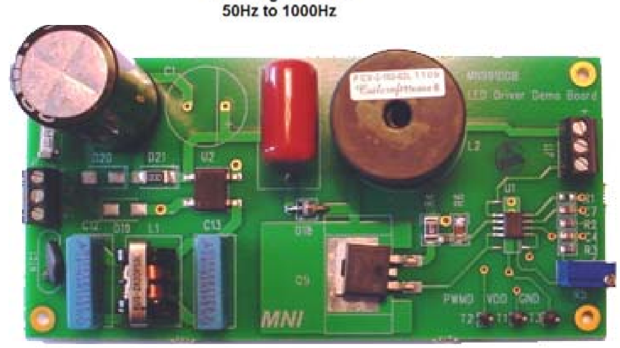
The layout of the MN9910DB-220 demo board is arranged to allow access to the pins of the MN9910B, facilitating analysis, probing, and experimentation. The IC footprint also allows both 8 and 16 pin versions of the man IC to be evaluated.

For IC details, please refer to the MN9910B datasheet



BOARD DESIGN TARGETS

Input Voltage:	180VAC – 240VAC
Load current:	175mA to 750mA
Series LED string:	18V to 50V
Switching Frequency:	48kHz (w/464k Rosc)
Efficiency:	90% (typ.)
Dimensions:	140.mm x 57.5mm



1. SAFETY INFORMATION

The MN9910DB-220 demo board, and thus everything connected to it, is connected through the bridge diodes to the Mains Voltage, with no isolation. While this can be acceptable for many applications, it is important that instrumentation connected to the Demo Board be isolated from Mains through transformer techniques, or by employing a floating ground supply to the test equipment. Though caution must be exercised in using the Demo Board, this condition is normal for laboratory work and even for certain applications where user contact with hot points is precluded.

2. LED CONNECTION

A High Brightness LED will typically have about 3.5V across it at high currents (consult your data sheet). This suggests that anywhere from 5 to 16 series LEDs can be connected to the MN9910DB-220.

Be sure to connect the LED load string before connecting to the Mains Supply. Wiring must be able to handle the high current-levels provided by this device.

Note that the Positive Terminal of the output jack is oriented more towards the center of the board's right edge.

3. JUMPER PINS

Note first that the jumper pins do not appear in alpha-numerical order.

T2: PWM Input Point
T1: Brings out the 7.8V Vdd created internal to MN9910B Controller IC
T3: Ground

Placing a jumper between T2 and T1 pulls the PWD node high, strapping the LED Driver constantly on.

If the jumper is removed, leaving T2 unconnected, a pull-down internal to the IC (~100k) forces the Driver Off.
For Dimming Control, remove the jumper and apply a Pulse-width modulated square wave to T2 (see next section).

4. PWM CONTROL

Pulse-width modulated control of the LED brightness is achieved by turning the drive on and off with a varying duty cycle. The human eye smoothes out the flicker for pulse frequencies of 50Hz or more. Above 1,000Hz, the on-off transition time for the driver will begin to encroach on the expected duty cycle. The PWM pin is designed to accept TTL-level voltages, but will allow the application of voltages up to the chip's internal Vdd.

5. LINEAR DIMMING

The on-board potentiometer will allow adjustment of the LED Current by adjusting the threshold at which peak current cyclically turns off the MOSFET Drive. If a current-sense probe is unavailable, the average current through the LED is sensed with an ammeter connected in series.

Normally, the internal threshold of 250mV directly relates to the LED peak current through the sense resistor.

The potentiometer presents a lower voltage than 250mV to an alternate internal comparator inside the IC, causing the LED current shut-off threshold to be lowered. This results in a lower peak LED current and thus lower overall LED current.

The potentiometer will reduce LED current when rotated clockwise. When this multi-turn trimmer reaches the end of its range, it will offer only slight resistance, so do not force it. When the board is unpowered, the resistance across the terminals of the 5k trimmer is very close to that presented to the circuit. It is suggested that users take an unpowered demo board and get acquainted with the trim pot, its setability and its manual feel.

6. DESIGN AND COMPONENT SELECTION

New users are often daunted by the number of design options available in an LED Driver. MNI suggests the following approach to guide component selection.

The first thing to establish is the desired LED Current Level. As-delivered, the MN9910DB_220 has been optimized for 350mA application, but with adjustments in component values, other levels can be achieved too. The following development uses the 350mA application.

The LEDs will be driven by a triangular current wave, which is generated by the current-mode control switching regulator, MN9910B. The LED Current will be the average of the peaks, I2 at the top and I1 at the low end (see Figure 1). It is customary to first set the delta-I (I2-I1) as a proportion of ILED. In LED Drivers, that proportion can be a higher than in standard Voltage regulators as peak-to-peak ripple is not as much of an issue for an LED current driver. The most important thing is that I1, the low-end of the LED current wave, not be allowed to ever touch zero. It was found that proportions of 0.3 to 1.0 are reasonable.

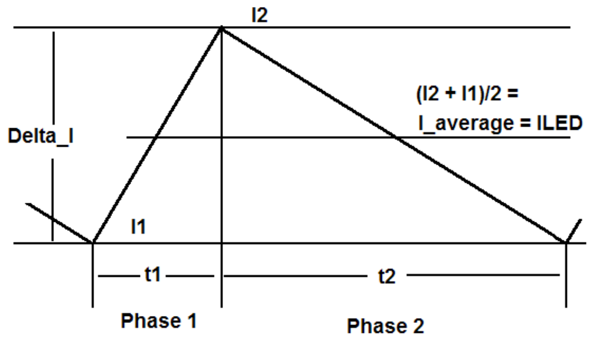


Figure 1. Current Wave Through LED Stack

Choosing a Ratio of Delta-I to ILED of 1.0 for this example, it is next found what I2 and I1 would be for the 350mA application.

For a known, target ILED, I2 and I1 are given by:

I2 = ILED(1 + Ratio/2)
I1 = ILED(1 - Ratio/2)

In this board case,

I2 = 350(1 + 0.50) = 525mA
I1 = 350(1 - 0.50) = 175mA

Then it is particularly interesting to know whether the Current-Sense resistor will play properly against the Feedback threshold set by the trimmer. In this board, only one R_sense resistor is employed, R4, and it has been selected at 0.27ohm. The trimmer circuit presents a voltage range of about 0.100V to 0.200V to the MN9910B. The peak value of I2 * R4 must be within the range of the trimmer adjustability. In this case, it is found

V2 = I2 * R4 = 525mA * 0.27V = 141.75mV

This is within the adjustability of the trim circuit. If this criteria was not met, then R_Sense would have to be adjusted. The trim range will always have to have the high-end limit placed below 250mV, which is the threshold of the internal feedback comparator if no trim connection is made to the LD pin.

The next sequence in the design will pursue the inductor and frequency selection. The associated design equations that enable rapid inductor and oscillator frequency selection are now presented.

Delta_I will be the same whether the current is rising, in Phase_1, or else falling, in Phase_2. In each of these two phases, the voltage across the inductor is different.

Ignoring the on-voltage of the FET, and other small losses ...

V1 = Vdc – VLEDs and V2 = VLEDs + Vdiode

Where

- Vdc is the rectified and filtered voltage appearing at the top of filtering capacitor C8. It was found this to be about 300V for 220VacRMS coming in, and 350mA Load.

- VLEDs is the LED stack voltage

and

- Vdiode is the forward drop of the free-wheeling diode.
Inductor dynamics are governed by the equation

V(L) = L * di/dt

The triangular current wave is very linear in both phases, so the expression is rewritten as:

Delta_I = V * Delta_t / L.

Since Delta_I is the same for both phases, it can be written

V2 * t2 / L = V1 * t1 / L

And since L is the same for all time, it can also be written

t1 = t2* V2/V1

Where

t1 and t2 are the ramp times in Phase_1 and Phase_2, respectively.

Also, Tosc (The Oscillator Period) is given by:

Tosc = t2 + t1.

Substituting for t1 ...

Tosc = t2 * [1 + V2/V1]

With Tosc expressed in terms of t2, the user gains the most insight on the relationship between Inductor selection, load voltage, load current, and oscillator frequency. Knowing that ...

t2 = L * Delta_I/V2 (as stated above))

It can be written:

Tosc = [1+ V2/V1] * L * Delta_I / V2

And also knowing that:

Delta_I = (Ratio) * ILED = (1.0) * ILED
V2 = VLEDs + Vdiode
V1 = Vdc - VLEDs

It can be written:

Tosc = [(Vdc+Vdiode) / (Vdc-VLEDs)] *
1.0 * ILED *L / (VLEDs + Vdiode)

This suggests that if this particular inductor is chosen, the oscillator period (frequency) must be made to track it.

Example:
The MN9910DB_220V is populated with L = 1mH. So, for the following target conditions:

Vdiode = 0.7V
Vdc = 300V (rectified / filtered 220VacRMS)
ILEDs = 350mA
VLEDs = 18V (5 LEDs at 350mA)

This yields:

Tosc =
[(300+0.7) / (300-18)] * 1.0 * 350mA * 1mH / (18 + 0.7)
Tosc = 20us
or
Fosc = 50kHz

The equation for the Oscillator Period (in us) is given by:

$$Tosc(\mu s) = (Rosc(k\Omega) + 22) / 25$$

By setting the oscillator for 20us period (50kHz), the current wave is made to conform to the limits of I2 and I1 chosen above. The 464kHz resistor already in the Demo Board will produce a frequency of about 51.4kHz. The 5k trimmer compensates for this slightly higher frequency by adjusting the threshold slightly down, since ILED will not have enough time to make the full swing excursion that was originally targeted. In practice, the trimmer converges all tolerances and variabilities into one adjustment.

Worst case analyses will consider variations in Vdc, frequency and every component tolerance in the mix.

BOUNDARY CONDITIONS: A second case example:

The development above is typical for an LED design. There are two boundary conditions which will drive any design using this IC. That would be the trim range relative to the Current Sense resistor, and the oscillator frequency.

The trimmer presents a voltage to the auxiliary comparator, and that voltage must be less than the built-in threshold of 250mV. The MN9910DB_220V Demo Board has been built with a range of about 100mV to 200mV coming off the trimmer. If no trim is desired, pin LD should be tied to +Vdd, so that the internal 250mV comparator takes over.

The sense resistor (R4) must play against that trim setting, to achieve the desired peak-to-peak value for ILED.

Suppose an application called for a much smaller Delta-I, perhaps 50% of the average ILED. Choosing a Ratio of Delta-I to ILED of 0.50, it is next found what I2 and I1 would be for the 350mA application.

I2 = ILED(1 + Ratio/2)
I1 = ILED(1 - Ratio/2)

In the present case,

I2 = 350(1 + 0.250) = 437.5mA
I1 = 350(1 - 0.250) = 262.5mA

Also:

Delta_I = Ratio * ILED = 0.50 * .350A
Delta_I = 0.175A

The key number is I2, the peak value of ILED. The trimmer must be able to satisfy the expression:

Vtrim = I2 *R_sense

And Vtrim must be well below 250mV. In the MN9910DB, this case study would yield Vtrim = o.4375A * 0.27ohm = 118mv, which is still within range for the trimmer. If this condition is not satisfied, the Sense resistor (R4) and/or the trimmer range must be adjusted.

A comprehensive expression, incorporating every remaining variable would provide insight as to what happens from here. Recognizing the importance of the oscillator period, this variable is kept isolated.

Tosc =
(Vdc + Vdiode)
--------------------------------------- * 2L* (Vtrim/R4-ILED)
(Vdc-VLEDs)(VLED+Vdiode)

Alternately:

Tosc =
(Vdc + Vdiode)
--- * L * Ratio * ILED
(Vdc - VLEDs)*(VLED + Vdiode)

The oscillator is best operated between 25kHz and 100kHz, or Tosc should lie between 10us and 40us. For nominal design, it is best to start by targeting Tosc in the center of the range, about 25us. Then L is chosen to sustain the balance of the equation. For these conditions:

Vdiode = 0.7V
Vdc = 300V (rectified and filtered 220VacRMS)
ILEDs = 350mA
VLEDs = 22V (6 LEDs at 350mA)

This yields:

25us =
(300 + 0.7)V
---------------------------------- * 0.50 * 0.35A * L
(300 - 22)V * (22 + 0.7)V

Rearranging and solving:

L = 3.0mH

The demo board is loaded with a resistor (464k) which provides a Tosc of ~20us. If this is satisfactory, the preferred inductor can be scaled at once to be

(20/25)* 3= 2.4mH.

If the inductor is not scaled, and the Tosc is kept at 25us, then the Ratio of ripple current to ILED will be automatically reduced through feedback to compensate.

INDUCTOR SUPPLIERS:

The demo board comes installed with a 1mH inductor. The manufacturer and part number appear in the BOM, which is part of this report. If it is replaced, be sure to select an inductor with ample current rating and low DC resistance.

The demo board purposely targets high-current inductors. with large footprints. Other suppliers that fit the footprint include:

Bourns 1140 Series:	e.g. 3.3mH = **1140-332K-RC**
muRata 1400 series	e.g. 4.7mH = **1447508C**

DUTY CYCLE CONSIDERATIONS:

As with any Buck regulator, the duty cycle, that is, the ratio of FET on-time to Tosc, should not be allowed to become 50% or higher. This condition would send the regulator into a Sub-Harmonic periodicity, in an attempt to find convergence.

Fortunately, with high input voltages typical for this application, and LED voltages in the low-to-mid 10's of volts, the duty cycle will rarely, if ever, approach 50%.

The duty cycle can be estimated as:

$$DC = \frac{(VLEDs + Vdiode)}{(Vdc + Vdiode)}$$

As long as Vdc is substantially more than double VLEDs, the duty cycle will not approach 50%.

HIGH VOLTAGE CONSIDERATIONS:

The output side of the Power MOSFET switches very fast, at a speed nearly independent of the load voltage. At very high bus voltages, the dv/dt impressed across the capacitance of the free wheeling diode, and other parasistics, creates noticeable current shoot-through at the time of MOSFET turn-on. This is considered normal.

It is manifest as voltage spikes on the Current-Sense resistor, especially at high mains voltages. For the 220V threshold. This consists of a grounded capacitor in the location of R6, and the manual application of a resistor between location R4 and R6.

The following guidelines will prove useful in assessing component choices in your system:

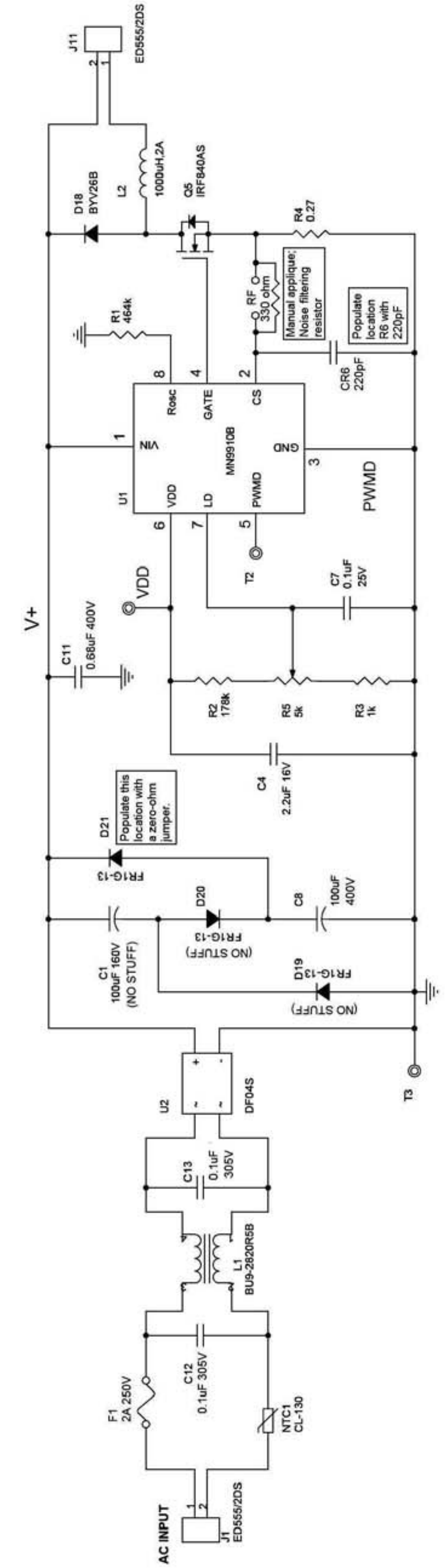
a - The nominal product of R x C must be between 70ns and 100ns
b - The resistor can be no less than 200ohms and no larger than 1kOhms
c - The total tolerance can be as high as 20% (resistor tolerance + capacitor tolerance)
d - The components must be mountable in the space available on the board

Acceptable examples:

330 Ohm x 220pF = 72.8ns
470 Ohm x 150pF = 70.5ns
1k Ohm X 100pF = 100ns

A schematic of the MN9910DB-220 appears in Figure 2, on the next page.

Figure 2. Schematic of MN9910DB_220V Demo Board



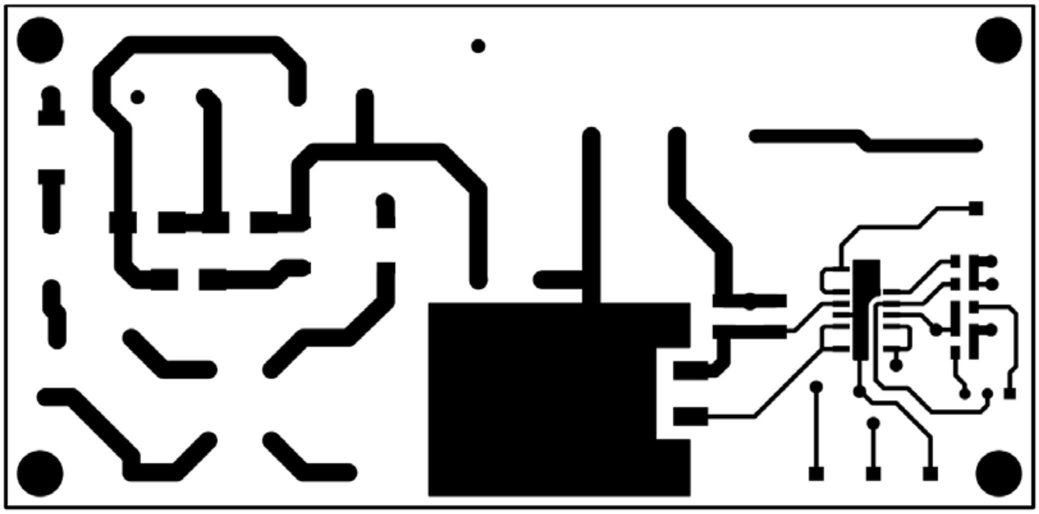
Bill of Materials

MN9910DB_220V_Rev1.0 - LED Driver Demo Board - 220V version

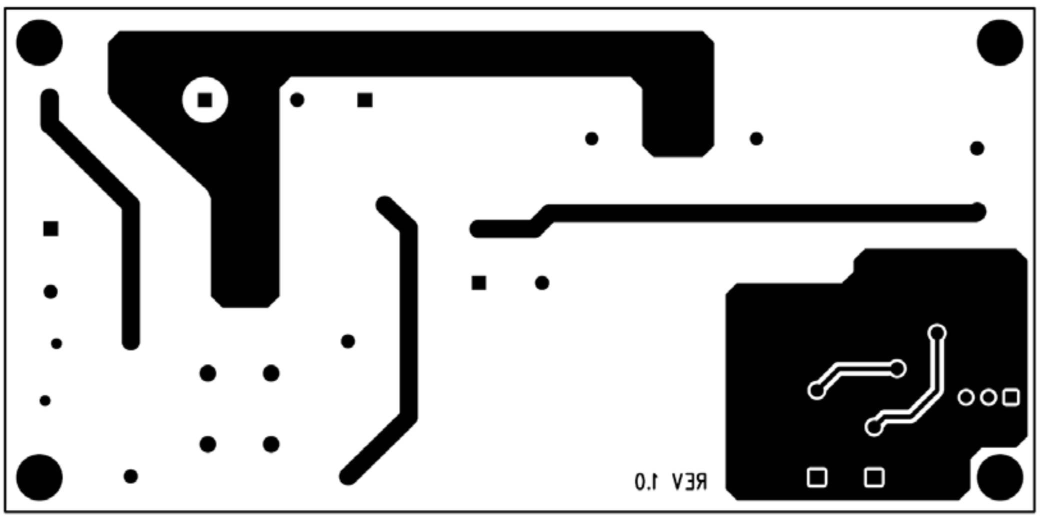
Revision: 1.0

Item	Quantity	Reference	Part	Manufacture	Part Number
1	0	C1	Do not stuff	-	-
2	1	C4	CAP CER 2.2µF, 16V SMD 0805	Panasonic	ECJ-2FB1C225K
3	1	C7	CAP CER 0.1µF, 25V SMD 0805	Panasonic	ECJ-2VF1E104Z
4	1	C11	0.68uF, 400V metalized polypropylene capacitor	Panasonic	ECW-F4684JB
5	2	C12,C13	0.1µF, 305V metalized polyester capacitors	**EPCOS**	B32922C3104M
6	1	D18	600V, 1.5A fast - soft recovery diode	Philips	BYV26C
7	1	D21	0 Ohm resistor		
8	1	F1	FUSE 2A 250V SMD	Shurter Electronics	3403.0169.11
9	2	J1,J11	TERMINAL BLOCK 3.5MM 2POS PCB	Onshore tech.	ED555/2DS
10	1	L1	IND CHOKE Low profile common mode	Coilcraft	BU9-2820R5B
11	1	L2	IND 1000µH, 2A	Coilcraft	PCV-2-105-02
12	4	MT1,MT2, MT3,MT4	NO LOAD	-	-
13	1	NTC1	CURRENT LIMITER INRUSH	Thermometrics	CL-130
14	1	Q5	MOSFET N-CH 500V 8A D2PAK	International Rectifier	IRF840AS
15	1	R1	RES 464K OHM 1/8W 1% 0805 SMD	Panasonic	ERJ-6ENF4643V
16	1	R2	RES 178K OHM 1/8W 1% 0805 SMD	Panasonic	ERJ-6ENF1783V
17	1	R3	RES 1.00K OHM 1/8W 1% 0805 SMD	Panasonic	ERJ-6ENF1001V
18	1	R4	RES .27 OHM 1/4W 5% 1210 SMD	Panasonic	ERJ-14RQJR27U
19	1	R5	TRIMMER POT 5K OHM TOP ADJ	BC components	CT-94W-502
20	3	T1,T2,T3	CONN HEADER .100 VERT TIN	Molex/Waldom	22-28-4030
21	1	U1	Universal LED driver	MNI	MN9910B
22	1	U2	RECT BRIDGE SMD 400V 1A 4P DF-S	Diodes, Inc.	DF04S
23	1	C8	100uF 400V electrolytic capacitor	Panasonic	EEU-EE2G101
24	1	RF	Manual Applique – 330ohm	Surface Mount	-
24	0	D19, D20	Do not stuff	-	-
25	1	(R6) CR6	Populate with 220pF Capacitor	Surface Mount	-

Top Traces of Board:



Bottom Traces of Board (as seen through the top):



Bottom Traces of Board (as seen from the back):