June 1996

FAIRCHILD SEMICONDUCTOR™

Application Note 42006

George A. Hall

Low Cost Electronic Ballast System Design

GENERAL DESCRIPTION

This application note describes a dimmable ballast system design using the ML4831 electronic ballast controller IC. This system can be evaluated using the ML4831EVAL kit. The ML4831EVALuation board is a low cost, improved version of Micro Linear's ML4830 dimmable ballast EVAL board. Careful attention was given to reducing the magnetic's cost of the EVAL board as well as other costly components. In addition, the design was improved to both increase and linearize the dimming range, eliminate lamp shut-off at low intensities, reduce visible standing waves and simplify the lamp-out protection circuitry. All components used are inexpensive and easy to obtain.

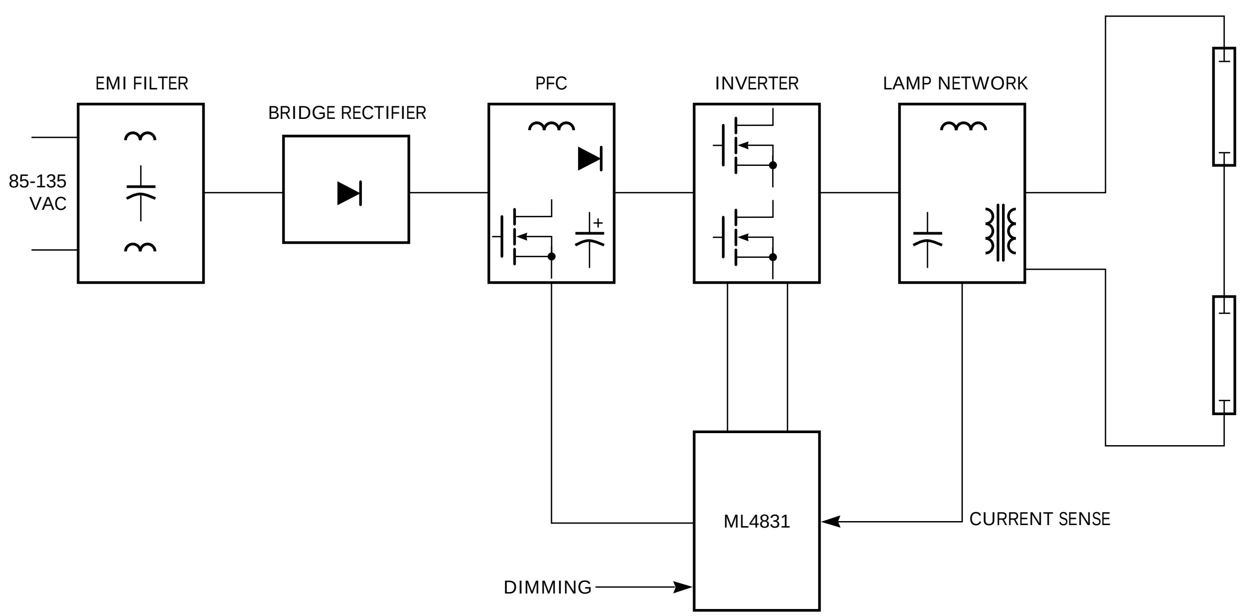
Operating from 85 to 135VAC line, the ML4831EVALuation board is a power factor corrected 60W electronic ballast with a dimming range capable of a 20:1 intensity change. Optimized to power two series connected T8 fluorescent bulbs, the ML4831EVAL board displays all the features of Micro Linear's latest ballast controller IC. The mode of operation used for pre-heat, striking and dimming of the bulbs is the widely accepted variable frequency, non-overlapping inverter topology. This EVAL board may be used with various bulbs other than T8's (such as T12's). See "Powering Other Fluorescent Lamps."

THEORY OF OPERATION

Figure 1 displays the block diagram of the ML4831EVAL board.

Applying AC line voltage to the EVAL board supplies start-up power to the ML4831 enabling gate drive for the PFC boost MOSFET Q1 and inverter FETs Q2 and Q3. PFC action generates a well regulated 205VDC supply for the lamp inverter circuit and steady-state supply voltage for the ML4831. The inverter stage consists of 2 totem pole configured N-channel power MOSFETs with their common node supplying the lamp network. The pair of MOSFETs are driven out of phase by the ML4831 with a 50% duty cycle. The lamp network is a parallel resonant circuit series-fed by the inverter transistors through a wave-shaping and current limiting inductor T3. The inductance of the resonant circuit is formed by T3's inductance and the primary inductance of the power transformer T4. The power transformer also provides safety isolation from the primary circuit to the bulbs. The lamp intensity is controlled by sampling the lamp current with current sensing transformer T5. T5's secondary current is converted to a voltage and fed to the ML4831's Lamp Feedback error amplifier. The amplifier output voltage varies in accordance with the amount of intensity required (set by potentiometer R23), internally adjusting the switching frequency to the inverter stage. The impedance characteristics of the lamp network results in lower lamp currents (and intensity) when the inverter stage frequency is increased.

BLOCK DIAGRAM



PERFORMANCE DATA

To measure system performance across the range of permissible input voltages use a variac or adjustable AC source.

A typical ML4831EVALuation board will have the following performance characteristics when operated as shown in the test conditions:

ML4831EVAL BOARD TEST RESULTS

	85VAC	120VAC	135VAC	Units
Efficiency	88	90	89	%
THD	2.32	2.12	2.35	%
P.F.	0.995	0.984	0.975	%

Test Conditions: 2 series wired T8 lamps (full intensity), 25°C
Equipment Used: Voltech Digital AC Power Analyzer #PM1000

The ML4831EVALuation board provides testpoints at the following circuit nodes:

TP1 GND
TP2 V_{CC}
TP3 INHIBIT
TP4 PFC Boost Voltage
TP5 Resonant Network (attenuated by 10x)

TYPICAL WAVEFORMS

Figures 2-5 display typical oscilloscope waveforms taken at various points on the eval board. A brief description precedes each figure. Test conditions and oscilloscope settings are given below each photo. The waveforms were taken with the eval board powering two series connected T8 bulbs.

PFC BOOST VOLTAGE (Fig. 2, TP4)

The DC bus for the inverter stage is derived from the rectified AC line. Note the 120Hz (2x line frequency) ripple voltage superimposed on the DC voltage. This is the result of the power factor correction of the AC line voltage. The peak to peak amplitude of the ripple voltage increases as the lamp intensity increases.

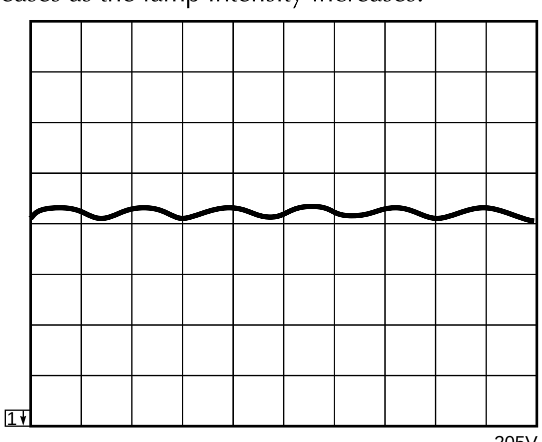


Figure 2. PFC Boost Voltage

Scope Setting: 100V/div, Horiz = 5ms/div
Test Conditions: Lamps @ maximum intensity, 120VAC
Equipment Used: Tektronix TDS540 Digitizing Scope

INVERTER VOLTAGE/CURRENT (Fig. 3)

The boosted DC bus voltage is chopped by Q2 and Q3 resulting in the square wave (upper trace) appearing at the input to the lamp network (Q2, Q3, T3 node). The resulting current in T3's primary winding appears in the bottom trace.

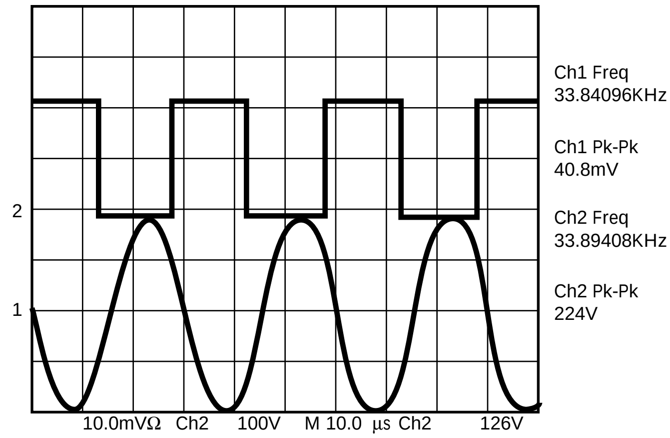


Figure 3. Inverter Output Voltage/Current

Scope Setting: Top = 100V/div, Bottom = 0.5A/div, Horiz = 10µs/div
Test Conditions: Lamps @ maximum intensity, 120VAC
Equipment Used: Tektronix TDS540 Digitizing Scope, Tektronix AM503 Current Probe Amplifier Assy

LAMP NETWORK VOLTAGE (Fig. 4, TP5)

The voltage at the T3, T4 and C19 node is so high as to warrant the use of an X100 probe for inspection. For safety and ease of visualization it is attenuated by 10x on the eval board by resistors R27, R28 and R29. Notice the positive DC offset voltage caused by the blocking capacitor C20. (The attenuator may not be needed for production).

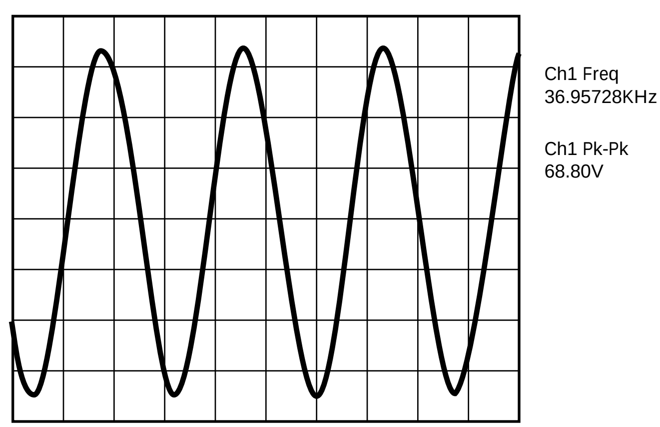


Figure 4. Lamp Network Voltage (atten. 10x)

Scope Setting: 10V/div, Horiz = 10µs/div
Test Conditions: Lamps @ maximum intensity, 120VAC
Equipment Used: Tektronix TDS540 Digitizing Scope

INVERTER/LAMP CURRENT (Fig. 5, T3 Pri, T4 Sec)

A comparison of the inverter current (same as Figure 5, lower trace) and lamp current is shown below. The phase difference is typical when an AC current source drives a parallel resonant network. There is however, no phase difference between the lamp current (T4 secondary current) and T4's primary current. The user will note an increase in the inverter current when the lamp current (and intensity) are decreased. This phenomena is a result of the decrease in total impedance of the lamp network at higher excitation frequencies and the "negative" resistance characteristic of the fluorescent lamp.

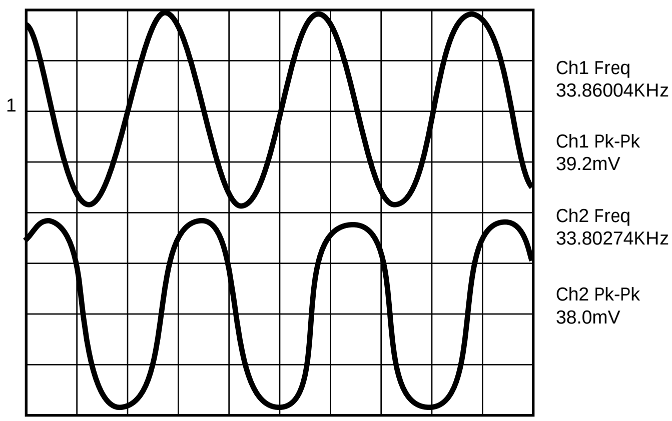


Figure 5. Inverter/Lamp Current

Scope Setting: Top = 0.5/div, Bottom = 0.1A/div, Horiz = 10µs/div
Test Conditions: Lamps @ maximum intensity, 120VAC
Equipment Used: Tektronix TDS540 Digitizing Scope, Tektronix AM503 Current Probe Amplifier Assy

LAYOUT CONSIDERATIONS

The ML4831EVAL Board contains high impedance, low level and low impedance, high level circuits and as such requires extra care in component placement, grounding and pc trace routing. This board makes use of a ground plane to achieve stable, noise free operation. When laying out a PC board for ballasts several precautions must be observed. The following list serves as a guide to ease the layout and minimize re-layout revisions.

1. Return the low side of the timing capacitor (C6) directly to the IC ground pin.
2. Bypass the reference and supply voltage pins directly to the IC ground pin with a 0.01µFd or greater low ESR capacitor.
3. Make a direct, low ohmic connection from the IC ground to the PFC current sense resistor (R1).
4. Return all compensation components directly to the IC ground pin, keeping the lead lengths as short as possible.
5. Use a ground plane (if permissible) for all low side (ground) connection points.
6. Whether using a ground plane or a single point ground layout, use heavy traces form the sense resistor/Q1 source node.
7. Separate rapidly changing waveforms; such as Q1's drain, from sensitive, high impedance circuits, such as the timing capacitor, PFC current sense input, error amplifier input/output, etc.

POWERING OTHER FLUORESCENT LAMPS

The ML4831EVAL Board design was optimized to power T8 lamps with cathodes requiring pre-heating prior to ignition. With little or no circuit modifications, other lamps can be driven with this board. For example, this EVAL board was used to power T12 lamps. Due to the different impedance of these lamps, the board delivers about 8 watts (4 watts/lamp) less.

For higher wattage lamps the PFC boost voltage can be increased by either increasing the value of R12 and R9 or decreasing the value of R13. Use extreme caution when attempting this as C11's voltage rating of 250V may be exceeded resulting in venting or catastrophic failure of the capacitor!!!

Lower wattage bulbs may not require any circuit modification, however, because of different lamp impedance characteristics, it may be necessary to decrease R5's (RSET) value to allow lower lamp intensities. Increasing T5's primary turns may also be necessary to achieve lower lamp intensities.

For rapid start lamps, adjusting the value R15 and C13 will shorten the pre-heat time while removing these components will eliminate the pre-heat time. See the ML4831 data sheet for details.

Instant start lamps have no cathode(s) and therefore no need for pre or sustained heating. If desired, remove R15 and C13 and employ the connection technique shown in Figure 6. For operator safety and to avoid circuit failure insulate any remaining wires from the EVAL board.

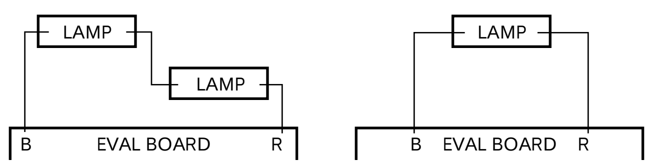


Figure 6. Dual/Single Instant-Start Lamp Connections

TABLE 1: PARTS LIST FOR THE ML4831EVAL EVALUATION KIT

CAPACITORS

QTY.	REF.	DESCRIPTION	MFR.	PART NUMBER
2	C1, 2	3.3nF, 125VAC, 10%, ceramic, “Y” capacitor	Panasonic	ECK-DNS332ME
1	C3	0.33µF, 250VAC, “X”, capacitor	Panasonic	ECQ-U2A334MV
4	C4, 8, 9, 22	0.1µF, 50V, 10%, ceramic capacitor	AVX	SR215C104KAA
2	C5, 21	0.01µF, 50V, 10%, ceramic capacitor	AVX	SR211C103KAA
1	C6	1.5nF, 50V, 2.5%, NPO ceramic capacitor	AVX	RPE121COG152
2	C7, 12	1µF, 50V, 20%, ceramic capacitor	AVX	SR305E105MAA
1	C10	100µF, 25V, 20%, electrolytic capacitor	Panasonic	ECE-A1EFS101
1	C11	100µF, 250V, 20%, electrolytic capacitor	Panasonic	ECE-S2EG101E
1	C13	4.7µF, 50V, 20%, electrolytic capacitor	Panasonic	ECE-A50Z4R7
3	C14, 15, 17	0.22µF, 50V, 10%, ceramic capacitor	AVX	SR305C224KAA
1	C16	1.5nF, 50V, 10%, ceramic capacitor	AVX	SR151V152KAA
1	C19	22nF, 630V, 5%, polypropylene capacitor	WIMA	MKP10, 22nF, 630V, 5%
1	C20	0.1µF, 250V, 5%, polypropylene capacitor	WIMA	MKP10, 0.1µF, 250V, 5%
1	C23	0.068µF, 160V, 5%, polypropylene capacitor	WIMA	MKP4, 68nF, 160V, 5%
1	C24	220µF, 16V, 20%, electrolytic capacitor	Panasonic	ECE-A16Z220
1	C25	47nF, 50V, 10%, ceramic capacitor	AVX	SR211C472KAA
1	C26	330pF, 50V, 10%, ceramic capacitor	AVX	SR151A331JAA
1	C27	22µF, 10V, 20%, electrolytic capacitor	Panasonic	ECE-A10Z22
RESISTORS:				
1	R1	0.33Ω, 5%, 1/2W, metal film resistor	NTE	HWD33
1	R2	4.3K, 1/4W, 5%, carbon film resistor	Yageo	4.3K-Q
2	R3, 26	47K, 1/4W, 5%, carbon film resistor	Yageo	47K-Q
1	R4	12K, 1/4W, 5%, carbon film resistor	Yageo	12K-Q
1	R5	20K, 1/4W, 1%, metal film resistor	Dale	SMA4-20K-1
1	R6	360K, 1/4W, 5%, carbon film resistor	Yageo	360K-Q
1	R7	36K, 1W, 5%, carbon film resistor	Yageo	36KW-1-ND
3	R8, 22, 11	22Ω, 1/4W, 5%, carbon film resistor	Yageo	22-Q
1	R9	402K, 1/4W, 1%, metal film resistor	Dale	SMA4-402K-1
1	R10	17.8K, 1/4W, 1%, metal film resistor	Dale	SMA4-17.8K-1
1	R12	475K, 1/4W, 1%, metal film resistor	Dale	SMA4-475K-1
1	R13	5.49K, 1/4W, 1%, metal film resistor	Dale	SMA4-5.49K-1

TABLE 1: PARTS LIST FOR ML4831EVAL EVALUATION KIT (Continued)

RESISTORS: (Continued)

QTY.	REF.	DESCRIPTION	MFR.	PART NUMBER
4	R14, 17, 24, 25	100K, 1/4W, 5%, carbon film resistor	Yageo	100K-Q
1	R15	681K, 1/4W, 5%, carbon film resistor	Yageo	681K-Q
2	R16, 29	10K, 1/4W, 1%, metal film resistor	Dale	SMA4-10K-1
1	R18	4.7K, 1/4W, 5%, carbon film resistor	Yageo	4.7K-Q
1	R21	33Ω, 1/4W, 5%, carbon film resistor	Yageo	33-Q
1	R23	25K, pot (for dimming adjustment)	Bourns	3386P-253-ND
1	R27	48.7K, 1/4W, 1%, metal film resistor	Dale	SMA4-48.7K-1
1	R28	41.2K, 1/4W, 1%, metal film resistor	Dale	SMA4-41.2K-1
DIODES:				
4	D1, 2, 3, 4	1A, 600V, 1N4007 diode (or 1N5061 as a substitute)	Motorola	1N4007TR
2	D5, 6	1A, 50V (or more), 1N4001 diodes	Motorola	1N4001TR
1	D7	3A, 400V, BYV26C or BYT03 fast recovery or MUR440 Motorola ultra fast diode	GI	BYV26C
8	D8, 9, 10, 11 12, 13, 14, 15	0.1A, 75V, 1N4148 signal diode	Motorola	1N4148TR
IC's:				
1	IC1	ML4831, Electronic Ballast Controller IC	Micro Linear	ML4831CP
TRANSISTORS:				
3	Q1, 2, 3	3.3A, 400V, IRF720 power MOSFET	IR	IRF720
MAGNETICS:				
1	T1	T1 Boost Inductor, E24/25, 1mH, Custom Coils P/N 5039 or Coiltronics P/N CTX05-12538-1 E24/25 core set, TDK PC40 material 8-pin vertical bobbin (Cosmo #4564-3-419), Wind as follows: 195 turns 25AWG magnet wire, start pin #1, end pin #4 1 layer mylar tape 14 turns 26AWG magnet wire, start pin #3, end pin #2 NOTE: Gap for 1mH ±5%		
1	T2	T2 Gate Drive Xfmr, L_{PRI} = 3mH, Custom Coils P/N 5037 or Coiltronics P/N CTX05-12539-1 Toroid Magnetics YW-41305-TC Wind as follows: Primary = 25 turns 30AWG magnet wire, start pin #1, end pin #4 Secondary = 50 turns 30AWG magnet wire, start pin #5, end pin #8		

TABLE 1: PARTS LIST FOR ML4831EVAL EVALUATION KIT (Continued)

QTY.	REF.	DESCRIPTION	MFR.	PART NUMBER
MAGNETICS: (Continued)				
1	T3	T3 Inductor, L_{PRI} = 1.66mH, Custom Coils P/N 5041 or Coiltronics P/N CTX05-12547-1 E24/25 core set, TDK PC40 material 10 pin horizontal bobbin (Plastron #0722B-31-80) Wind as follows: 1st: 170T of 25AWG magnet wire; start pin #10, end pin #9. 1 layer of mylar tape 2nd: 5T of #32 magnet wire; start pin #2, end pin #1 1 layer of mylar tape 3rd: 3T of #30 Kynar coated wire; start pin #4, end pin #5 4th: 3T of #30 Kynar coated wire; start pin #3, end pin #6 5th: 3T of #30 Kynar coated wire; start pin #7, end pin #8 NOTE: Gap for 1.66mH ±5% (pins 9 to 10)		
1	T4	T4 Power Xfmr, L_{PRI} = 3.87mH, Custom Coils P/N 5038 or Coiltronics P/N CTX05-12545-1 E24/25 core set, TDK PC40 material 8 pin vertical bobbin (Cosmo #4564-3-419) Wind as follows: 1st: 200T of 30AWG magnet wire; start pin #1, end pin #4. 1 layer of mylar tape 2nd: 300T of 32AWG magnet wire; start pin #5, end pin #8 NOTE: Gap for inductance of primary: (pins 1 to 4) @ 3.87mH ±5%		
1	T5	T5 Current Sense Transformer, Custom Coils P/N 5040 or Coiltronics P/N CTX05-12546-1 Toroid Magnetics YW41305-TC Wind as follows: Primary = 3T 30AWG kynar coated wire, start pin #1, end pin #4 Secondary = 400T 35AWG magnet wire, start pin #5, end pin #8		
INDUCTORS:				
2	L1, 2	EMI/RFI Inductor, 600µH, DC resistance = 0.45Ω	Prem. Magnetics	SPE116A
FUSES:				
1	F1	2A fuse, 5 x 20mm miniature	Littlefuse	F948-ND
2		Fuse Clips, 5 x 20mm, PC Mount		F058-ND
HARDWARE:				
1		Single TO-220 Heatsink	Aavid Eng.	PB1ST-69
2		Double TO-220 Heatsink	IERC	PSE1-2TC
3		MICA Insulators	Keystone	4673K-ND

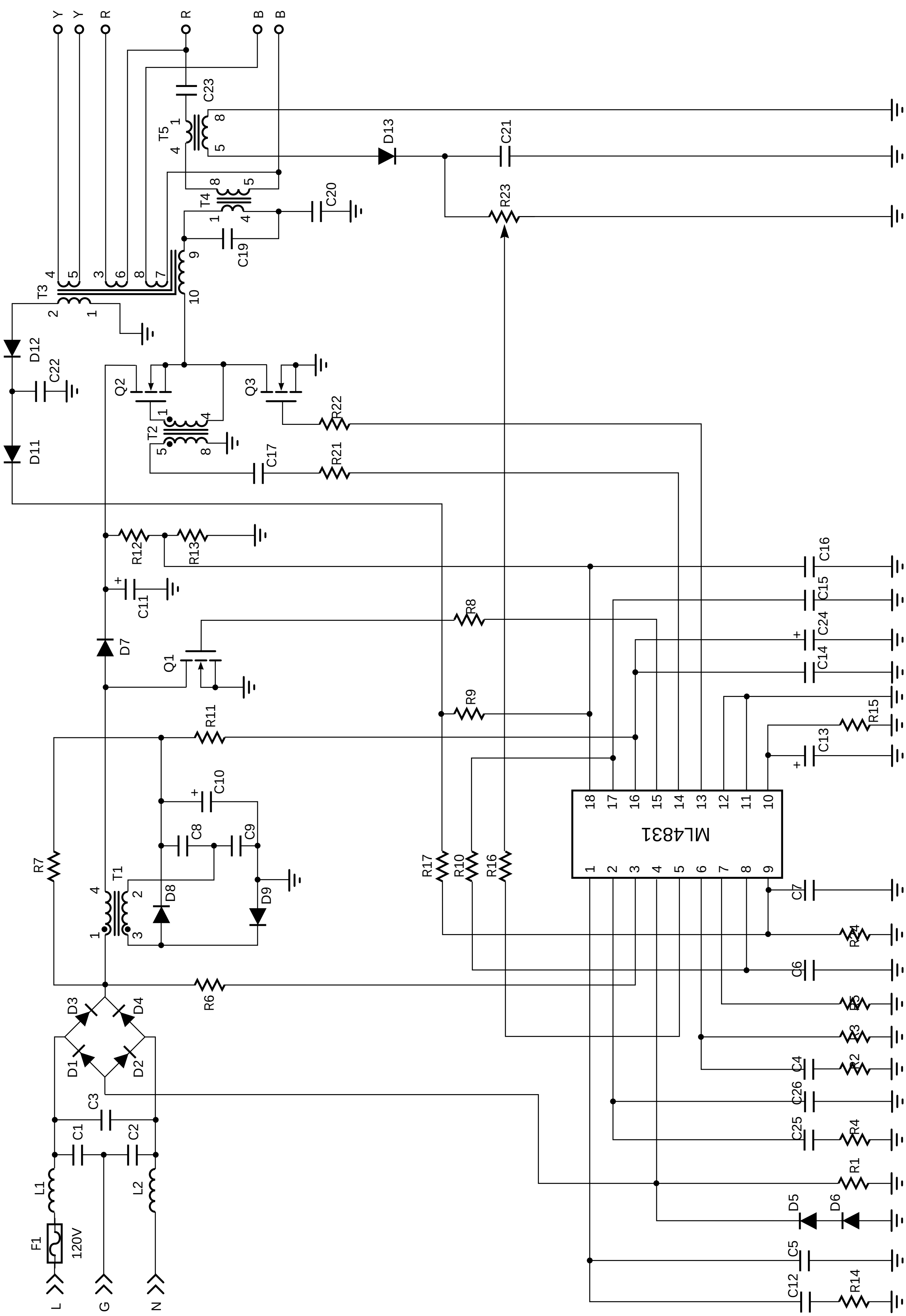


Figure 7. Circuit Schematic of the ML4831EVAL Evaluation Kit

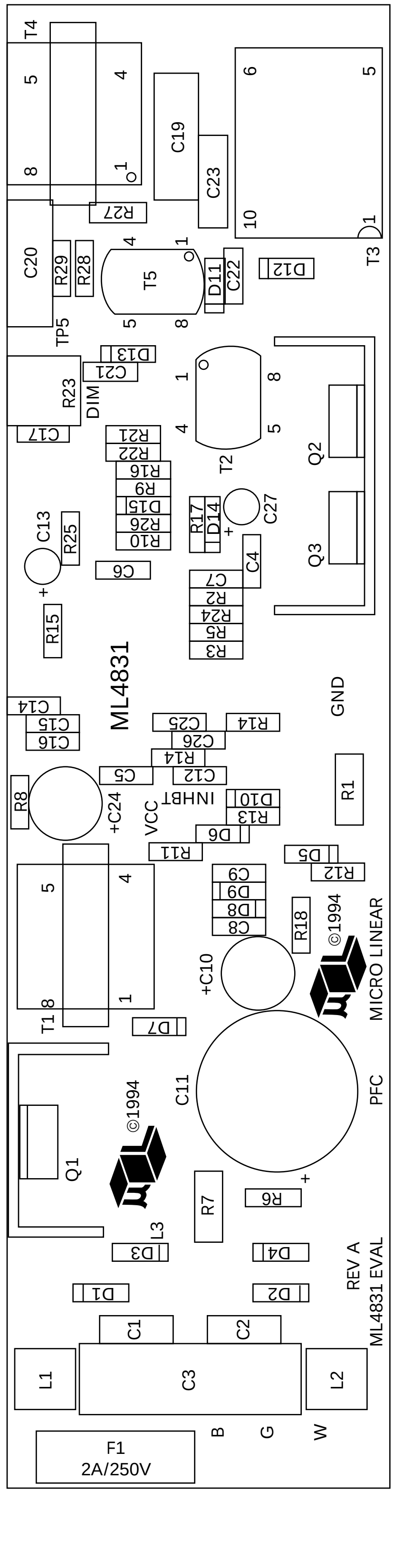


Figure 8. ML4831EVAL Component Silkscreen Layer

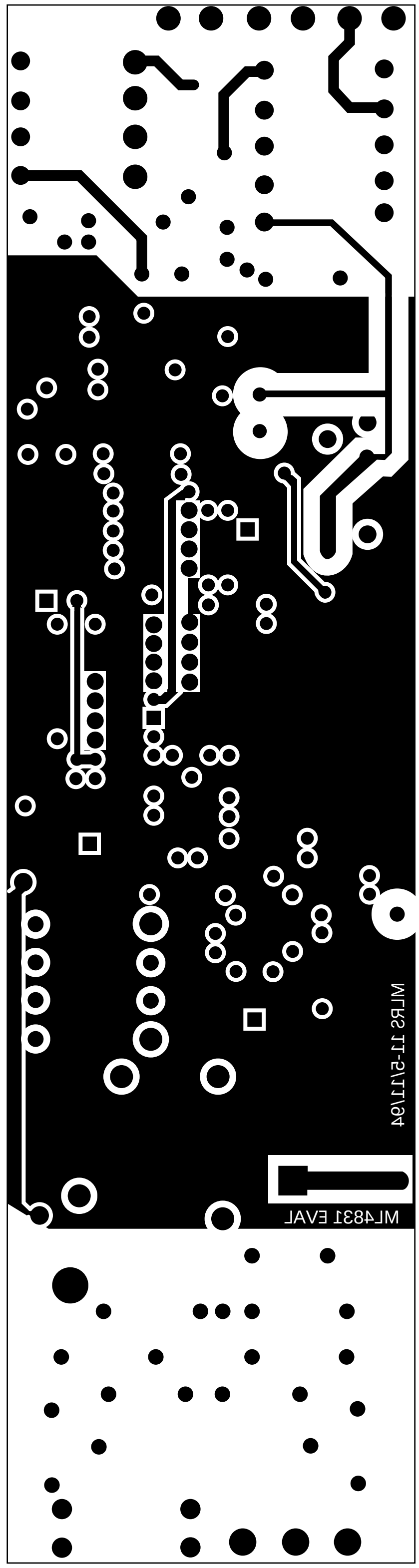


Figure 9. ML4831EVAL Ground Plane and Bottom Trace Layer

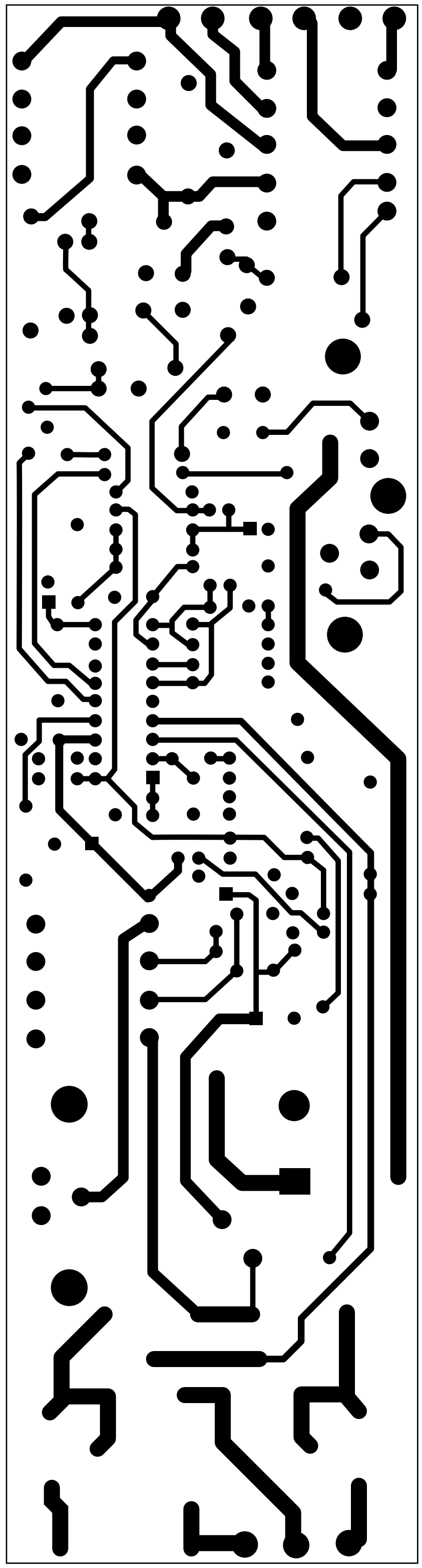


Figure 10. ML4831EVAL Top Trace Layer