Design Example Report

Title	***6 W / 11 W$_{PK}$ 3-Output Flyback Converter Using LinkSwitch™-4 LNK4004D***
Specification	185 VAC – 440 VAC Input; 3.3 V, 150 mA [4 V Output to be used with LDO as post regulator]; 8 V, 500 mA (1.2 A$_{PK}$); 12 V, 100 mA Outputs
Application	Energy Meter
Author	Applications Engineering Department
Document Number	DER-479
Date	May 19, 2015
Revision	1.8

Summary and Features

- LinkSwitch-4 emitter switch driver minimized switching losses at high input voltage
- Primary side control, no optocoupler, no TL-431
- Good cross regulation between the 3 outputs
- High efficiency >75% full load.
- <50 mW no load input power at 230 VAC
- Low cost / component count.

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Important Note:
Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

1 Introduction

This document describes a power supply with three non-isolated outputs utilizing the LNK4004D BJT controller.

The document contains the power supply specification, schematic, layout, bill of materials, transformer specification and performance data.

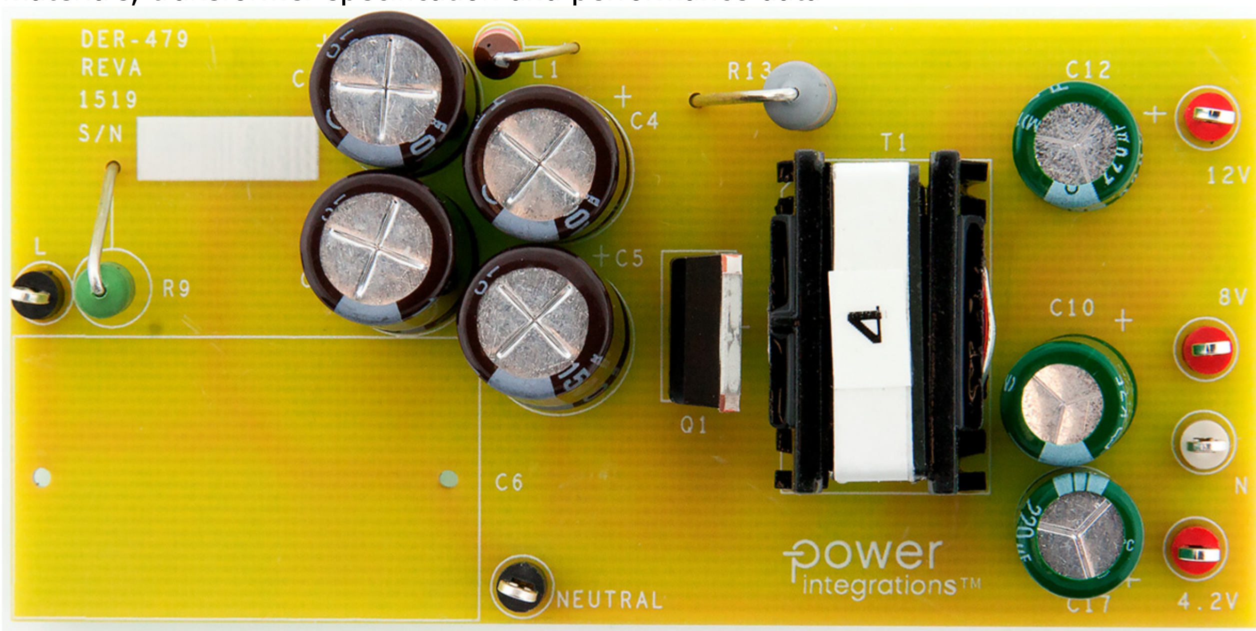

Figure 1 – Prototype Top View.

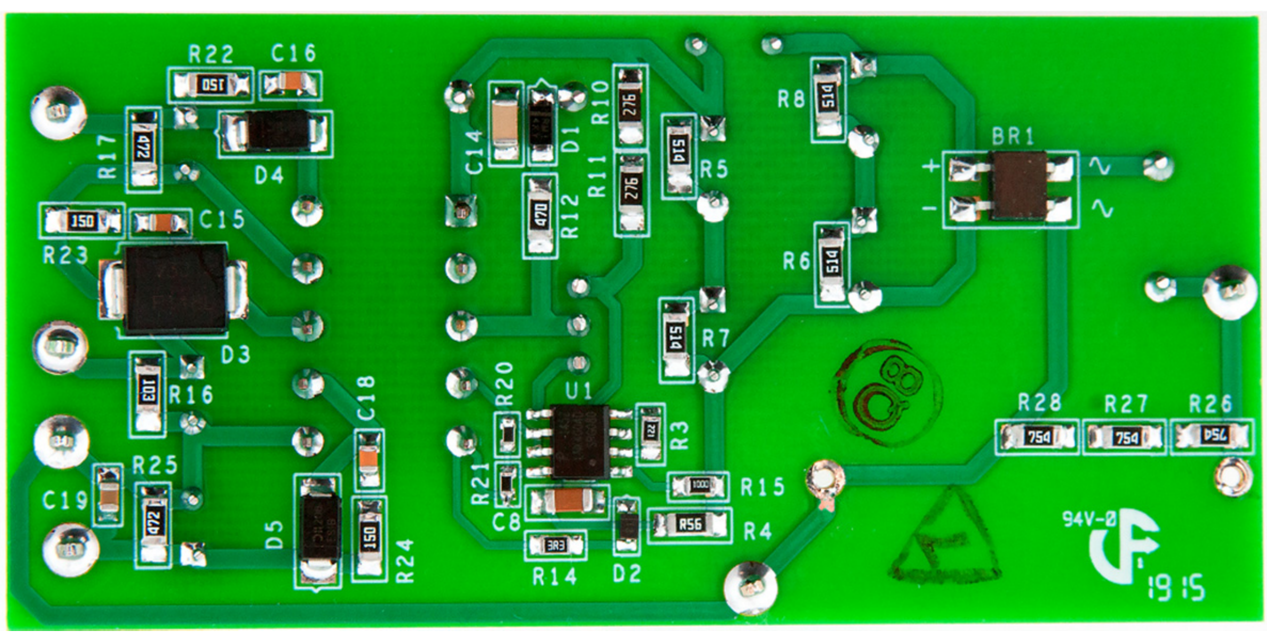

Figure 2 – Prototype Bottom View.

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2 Power Supply Specification

The table below represents the minimum acceptable performance of the design. Actual performance is listed in the results section.

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	185	230	440	VAC	It should withstand for indefinite time 440 VAC at full load.
Frequency	f_{LINE}		50		Hz	
Output						
Output Voltage 1	V_{OUT1}		4		V	±8% [Input for 3.3V Post Regulator]
Output Ripple Voltage 1	$V_{RIPPLE1}$			50	mVpp	20 MHz bandwidth with steady-state load
Output Current 1	I_{OUT1}	10		150	mA	
Output Voltage 2	V_{OUT2}		8		V	±10%
Output Ripple Voltage 2	$V_{RIPPLE2}$			200	mVpp	20 MHz bandwidth with steady-state load
Output Current 2	I_{OUT2}	20		500	mA	
Output Peak Current 2	$I_{OUT\ PK2}$			1.2	A	
Output Voltage 3	V_{OUT3}		12		V	±10%
Output Ripple Voltage 3	$V_{RIPPLE3}$			500	mVpp	20 MHz bandwidth with steady-state load
Output Current 3	I_{OUT3}	30		100	mA	
Total Output Power						
Peak Output Power	$P_{OUT\ PK}$			11	W	
Continuous Output Power	P_{OUT}	0		6	W	
Efficiency						
Full Load Efficiency	η		75		%	@ 230 VAC Input and Full Load, 25 °C
Environmental						
No Load Input Power	P_{IN-OL}		50		mW	Without X-capacitor, bleeder resistors and balancing resistors and 230 VAC Input
Conducted EMI		Meets CISPR22B/ EN55022B				
Ambient Temperature	T_{AMB}	0		85	°C	Open frame, free convection, sea level

Note: This power supply provides a 4 V output voltage. A 3.3 V linear regulator should be used to obtain regulated supply for the meter circuit. A 4 V output ensures sufficient headroom for an LDO 3.3 V regulator.

3 Schematic

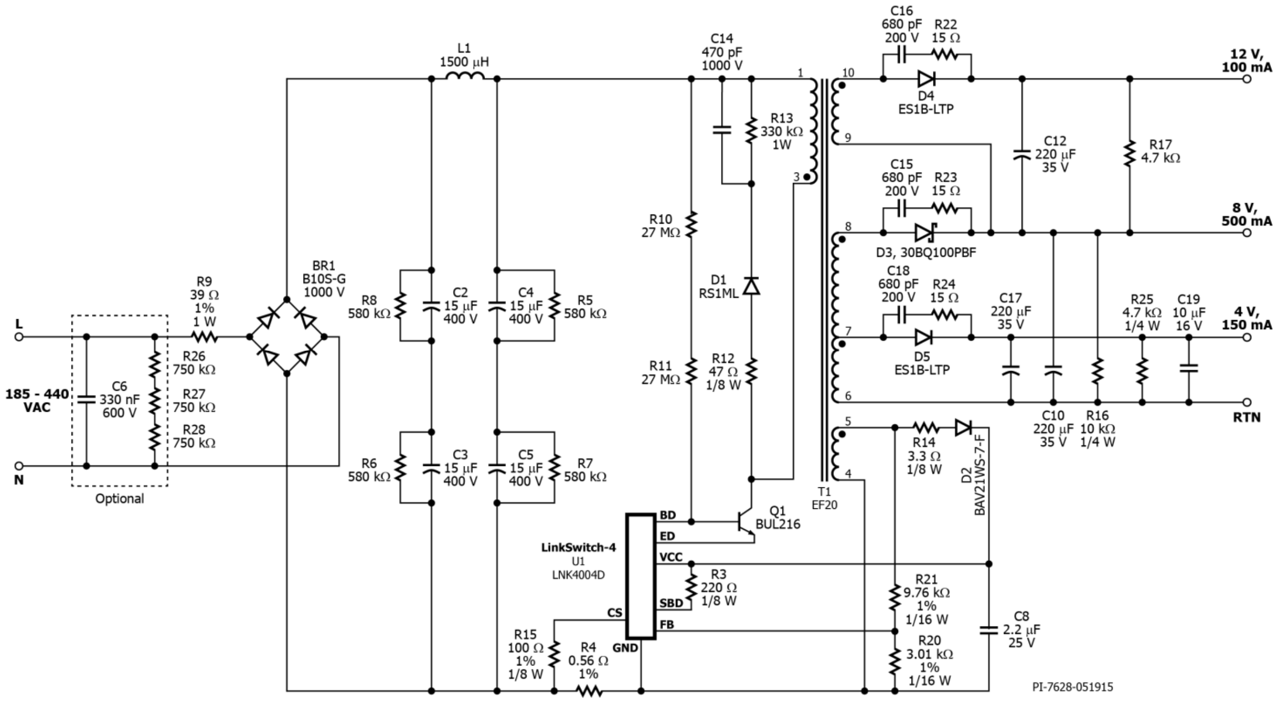

Figure 3 – Schematic.

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4 Circuit Description

The schematic in Figure 3 shows a flyback converter using the BJT controller LNK4004D*.* The circuit is designed to operate from 185 VAC to 290 VAC (withstand 440 VAC for indefinite time at full load) input and provides three non-isolated outputs (3.3 V / 150 mA, 8 V / 500 mA (1.2 A_{PK}) and 12 V / 100 mA). The 3.3 V output is to be derived from the 4 V output with a linear voltage regulator. All voltages are referred to Neutral.

4.1 Input Stage

The input stage consists of a fusible resistor R9, bridge rectifier BR1, capacitors C2, C3, C4 and C5 implementing full wave rectifier and filter. Inductor L1 together with capacitors C2, C3, C4 and C5 forms a π-filter which provides filtering for differential EMI. Capacitor C6 is required to further attenuate conducted noise if EMI filtering is not present in the system where this power supply is to be used. Resistors R26, R27 and R28 are required to be installed on the board if capacitor C6 is used so as to discharge C6 when input supply is removed.

Resistors R5, R6, R7 and R8 are used to balance (equalize) the voltage across the series connected capacitors in the rectifier stage.

4.2 LNK4004D Controller

The LinkSwitch-4 family adaptive BJT drive technology uses combined base and emitter switching to boost switching performance and deliver higher efficiency, wider Reverse Bias Safe Operating Area (RBSOA) margin and the flexibility to accommodate a wide range of low cost BJT. The device incorporates a multimode PWM/PFM controller with quasi resonant switch to maximize the efficiency. A high-voltage BJT has been selected to easily withstand 440 VAC input requirements guaranteeing a 15% margin. Across transformer T1's primary a clamp network is connected consisting of diode D1, resistors R12, R13 and capacitor C14 which clamp the voltage spike at each turn off of Q1(due to transformer primary leakage inductance) and thus protecting Q1.

When the input is first applied, resistors R10 and R11 provide base bias to the transistor Q1 which in turn provides charging current to capacitor C8. Once the capacitor C8 is charged, IC U1 can start switching.

4.3 Output Rectification

The non-isolated outputs are derived from transformer T1's secondary's by means of rectifier diodes D3, D4, D5, and filter capacitors C10, C12 and C17. RC networks are connected across diodes D3, D4 and D5 which damp the ringing and high voltage spikes across the diodes that result from leakage reactance of the secondary windings.

A ceramic capacitor C19 is connected across the 4 V output to filter high frequency ripple. Resistors R16, R17, and R25 act as preloads for the 8 V, 12 V and 4 V outputs respectively.

4.4 Output Feedback and Control

Constant output voltage regulation is achieved by sensing the voltage at the feedback input, which is connected to the voltage supply winding. The feedback waveform is continuously analyzed and sampled at time t_{SAMP} to measure the output voltage. The timing instant t_{SAMP} is identified by the slope of the feedback waveform and is coincident with zero flux in the transformer. The sampled voltage is regulated at $V_{FB(REG)}$ by the voltage control loop. The (typical) CV mode output voltage is set by the ratio of resistors R20 and R21 (see Figure 3) and by the transformer turns ratio, according to the following formula (where output diode voltage is neglected):

$$V_{OUT(CV)} = V_{FB(REG)} \, x \left(1 + \frac{R_{FB1}}{R_{FB2}}\right) x \left(\frac{Ns}{Nf}\right)$$

N_F is the number of turns on the feedback (or voltage supply if used for feedback) winding and N_s is the number of turns on the secondary winding. The tolerance of R_{FB1} and R_{FB2} affect output voltage regulation and main estimation so should typically be chosen to be 1% or better.

Resistor R4 is used to sense the primary side current by the controller IC U1.

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5 PCB Layout

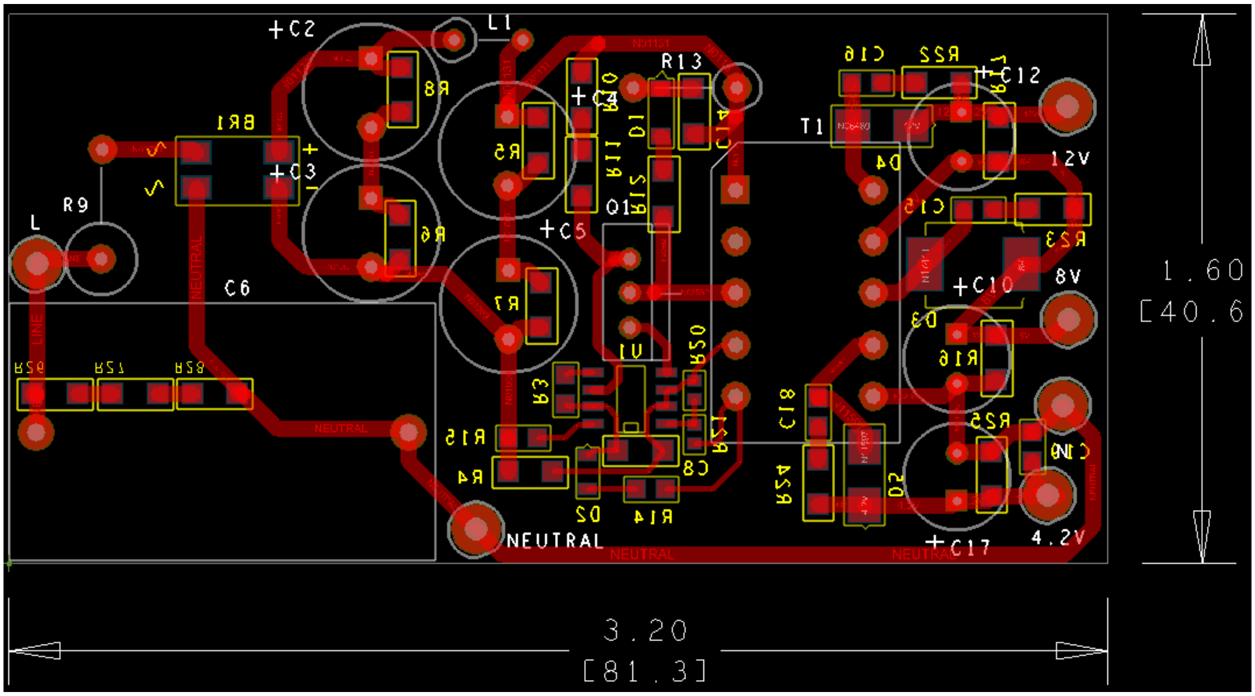

Figure 4 – PCB Bottom Side.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	3	12 V 4.2 V 8 V	Test Point, RED, THRU-HOLE MOUNT	5010	Keystone
2	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip Tech
3	4	C2 C3 C4 C5	15 μF, 400 V, Electrolytic, (10 x 16)	UVC2G150MPD	Nichicon
4	1	C6	0.33 μF, 600 V, Metallized Polypropylene, X1 cap	PHE845VF6330MR06L2	Kemet
5	1	C8	2.2 μF, 25 V, Ceramic, X7R, 1206	TMK316B7225KL-T	Taiyo Yuden
6	3	C10 C12 C17	220 μF, 35 V, Electrolytic, Very Low ESR, 56 mΩ, (8 x 15)	EKZE350ELL221MH15D	Nippon Chemi-Con
7	1	C14	470 pF, 1000 V, Ceramic, COG, 1206	VJ1206A471JXGAT5Z	Vishay
8	3	C15 C16 C18	680 pF 200 V X7R Ceramic ±10 %	C0805C681K2RACAUTO	Kemet
9	1	C19	10 μF, 16 V, Ceramic, X5R, 0805	GRM21BR61C106KE15L	Murata
10	1	D1	1000 V, 800 mA, Fast Recovery SMF, 5000 ns,	RS1ML	Taiwan Semi
11	1	D2	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
12	1	D3	100 V, 3 A, Schottky, SMC	30BQ100PBF	Vishay
13	2	D4 D5	100 V, 1 A, Superfast, 35 ns, DO-214AC, SMA	ES1B-LTP	Micro Commercial
14	2	L NEUTRAL	Test Point, BLK, THRU-HOLE MOUNT	5011	Keystone
15	1	L1	1500 μH, 100 mA, 23 Ohm, Axial Ferrite	B78108S1155J	Epcos
16	1	N	Test Point, WHT, THRU-HOLE MOUNT	5012	Keystone
17	1	Q1	NPN, 800 V, 4 A, TRANS, TO-220	BUL216	ST Micro
18	1	R3	220 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ221V	Panasonic
19	1	R4	0.56 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8RQJR56V	Panasonic
20	4	R5 R6 R7 R8	560 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ564V	Panasonic
21	1	R9	39.0 Ω, 1%, 1 W, Wirewound	PAC100003909FA1000	Vishay
22	2	R10 R11	27 MΩ, 5%, 1/4 W, Thick Film, 1206	RV1206JR-0727ML	Yageo
23	1	R12	47 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ470V	Panasonic
24	1	R13	330 kΩ, 5%, 1 W, Metal Oxide	RSF100JB-330K	Yageo
25	1	R14	3.3 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ3R3V	Panasonic
26	1	R15	100 Ω, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1000V	Panasonic
27	1	R16	10 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ103V	Panasonic
28	2	R17 R25	4.7 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ472V	Panasonic
29	1	R20	3.01 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3011V	Panasonic
30	1	R21	9.76 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF9761V	Panasonic
31	3	R22 R23 R24	15 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ150V	Panasonic
32	3	R26,R27,R28	750 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ754V	Panasonic
33	1	T1	Bobbin, EF20, Vertical, 10 pins	B-EF20V-10-1-PET	Lodestone
34	1	U1	LinkSwitch-4, 12 W, SO-8	LNK4004D	Power Integrations

Note: Resistors R26, R27 and R28 and Capacitor C6 are required only if the meter circuit does not have an EMI filter.

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7 Transformer Design Spreadsheet

ACDC_LinkSwitch-4_121914; Rev.1.0; Copyright Power Integrations 2014	**INPUT**	**INFO**	**OUTPUT**	**UNIT**	**LinkSwitch-4_121914: LinkSwitch-4 Discontinuous Flyback Transformer Design Spreadsheet**
ENTER APPLICATION VARIABLES					
VACMIN	185		185	Volts	Minimum AC Input Voltage
VACMAX	290		290	Volts	Maximum AC Input Voltage
fL			50	Hertz	AC Mains Frequency
VO	11.70		11.70	Volts	Output Voltage at the end of the cable
VO_PCB			11.70	Volts	Output Voltage at PCB
IO	1.10		1.10	Amps	Nominal output current during CC
PO			12.87	Watts	Typical output power including cable drop compensation
n			0.80	%/100	Efficiency Estimate
Z			0.50		Loss allocation factor
tC			3.00	ms	Bridge Rectifier Conduction Time Estimate
CIN	15.0		15.0	uFarads	Total input bulk Capacitance
ENTER LINKSWTCH-4 VARIABLES					
LinkSwitch-4	LNK40X4D				Select LNK-4
Cable drop compensation option	0%		0%		Select level of cable drop compensation
DEVICE		Info	LNK4004D		Output Power is greater than datasheet PO for this part number. Please verify performance on bench or select a bigger part
VCS_MIN	56		56	mV	Selection of Vcsmin
RCS2			100	Ohm	Resistance that corresponds to the selected Vcsmin
FSW			65000	Hertz	LinkSwitch-4 typical switching frequency
FSW_MIN			60000	Hertz	LinkSwitch-4 minimum switching frequency
FSW_MAX			70000	Hertz	LinkSwitch-4 maximum switching frequency
ILIM_MAX			1.10	A	Maximum emitter pin sink current
VCS_TARGET	0.171	Info	0.171	Volts	
RCS			0.609	Ohm	Calculated RCS value
Transistor					
PART_NUMBER			TS13005		Example transistor for the current application
HFE_NOLOAD	20		20		Minimum DC current gain at no load
HFE	20		20		Minimum DC current gain for load transient
VSWMAX	1200		700	Volts	Switch Breakdown voltage
v_CGND_ON			3.0	Volts	BJT + LNK-4 on-state Collector to ground Voltage (3V if no better information available)
Additional Parameters					
Startup					
STARTUP_TIME			1.00	second	Desired startup time
R_STARTUP	54.00		54.00	MOhm	Startup resistor (default calculation assumes a standard resistor for 1 second desired startup)
STARTUP_TIME_FINAL			0.49	second	Final startup time assuming resistor value Rstartup
Dummy load and no load					

R_PRELOAD	20000		20000	Ohm	Pre load resistor (1%)
P_PRELOAD			6.84	mW	Preload resistor power consumption at no load
FSW_NOLOAD			721	Hz	Estimated switching frequency at no load
Load step and undershoot					
RCABLE_EST			0.000	Ohm	Estimated charger cable resistance
I_LOADSTEP	0.50		0.50	A	Required maximum current load step from zero load
V_UNDERSHOOT	0.50		0.50	V	Accepted undershoot during maximum load step
FSW_UNDERSHOOT			612	Hz	Minimum frequency at no load in order to satisfy undershoot requirements
Feedback Resistors					
V_UV+	182.00		182.00	V	DC voltage at which power supply will start up
RFB1			10200	Ohm	Initial estimate for top feedback resistor (std value, use 1% tolerance)
RFB2			3010	Ohm	Initial estimate for bottom feedback resistor (std value, use 1% tolerance)
Output Capacitor					
LOAD_TYPE	Resistive Load		Resistive Load		Select load type for startup testing. This will help estimate the maximum output capacitance that will allow proper startup under any normal operating conditions
IONOM		Info	0.94	A	Input is not applicable for this load type
R_LOAD			10.64	Ohm	Equivalent resistive load placed at the end of PCB for simulating load and cable
COUT_ADVISED			209	uF	Maximum Cout to guarantee proper startup and stability
COUT_FINAL	73		73	uF	Total output capacitance on the secondary of the power supply
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	EF20		EF20		Core Type
Custom Core (Optional)					If Custom core is used - Enter Part number here
Bobbin		EF20_BOBBIN		P/N:	*
AE			0.34	cm^2	Core Effective Cross Sectional Area
LE			4.49	cm	Core Effective Path Length
AL			1570	nH/T^2	Ungapped Core Effective Inductance
BW			12.20	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L			2		Number of Primary Layers
F_RES	700		700	kHz	Anticipated resonant frequency on the primary side (180<Ftrf<1200)
Turns Ratio / Secondary turns					
VOR	149.00	Warning	149.00	Volts	Reflected Output Voltage
NS	30		30		Number of Secondary Turns
Bias/Feedback Winding					
NB			21	Turns	Suggested number of turns for the bias / feedback winding
VDB			0.70	Volts	Bias Winding Diode Forward

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					Voltage Drop
VB_NOLOAD	7.80		7.80	Volts	Desired Bias voltage at no load
PB_NOLOAD			4.57	mW	Bias winding power consumption estimate at no load
VB_NOLOAD_MEASURED			7.80	Volts	Measured Bias voltage at no load
Bias Capacitor					
CBIAS	2.20		2.20	uF	Auxiliary capacitor. Default value assumes 1V of ripple on bias winding.
DELTAV_BIAS			378	mV	Voltage ripple on bias winding capacitor (should be between 0.05V and 1.6V
DC INPUT VOLTAGE PARAMETERS					
VMIN			231	Volts	Minimum DC Input Voltage
VMAX			410	Volts	Maximum DC Input Voltage
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.45		Maximum Duty Cycle (calculated at VMIN)
IAVG			0.07	Amps	Average Primary Current (calculated at VMIN)
IP			0.28	Amps	Peak Primary Current (calculated at full load, VMIN)
IP_TRANSIENT			0.57	Amps	Max Peak Primary Current during a load transient
IRMS			0.11	Amps	Primary RMS Current (calculated at VMIN)
KDP		Warning	0.79		Set KP above 1.0 to guarantee correct operation of the part.
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			6817	uHenries	Typical Primary Inductance
LP Tolerance	10		10		Tolerance of Primary Inductance
NP			360		Primary Winding Number of Turns
ALG			53	nH/T^2	Gapped Core Effective Inductance
BM			1585	Gauss	Maximum Flux Density at PO, VMIN, LP (BM<3000)
BP			3574	Gauss	Peak Flux Density (BP<4200) at ILIMITMAX and LP_MAX. Note: Recommended values for adapters and external power supplies <=3900 Gauss
BAC			626	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1675		Relative Permeability of Ungapped Core
LG			0.77	mm	Gap Length (Lg > 0.1 mm)
BWE			24.4	mm	Effective Bobbin Width
OD	0.17		0.17	mm	Maximum Primary Wire Diameter including insulation
INS			0.04	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.13	mm	Bare conductor diameter
AWG			36	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			25	Cmils	Bare conductor effective area in circular mils
CMA			230	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)
Primary Current Density (J)			#N/A	Amps/mm^2	#N/A
SECONDARY DESIGN PARAMETERS					
VO			11.70	Volts	Output Voltage (at PCB)
IO			1.10	Amps	Average Power Supply Output Current

VD	0.70		0.70	Volts	Output Winding Diode Forward Voltage Drop
PIVS			47	Volts	Output Rectifier Maximum Peak Inverse Voltage
ISP			3.37	Amps	Peak Secondary Current
ISRMS			1.46	Amps	Secondary RMS Current
IRIPPLE			0.96	Amps	Output Capacitor RMS Ripple Current
CMS			292	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			25	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.46	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.41	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
INSS			-0.03	mm	Maximum Secondary Insulation Wall Thickness
VOLTAGE STRESS PARAMETERS					
SWITCH_DERATING			0.10	%/100	Desired derating factor for switch
VDRAIN		Warning	743	Volts	Peak collector voltage may be too high. Verify performance on bench
PIVS			60	Volts	Output Rectifier Maximum Peak Inverse Voltage
PIVB			41	Volts	Bias Rectifier Maximum Peak Inverse Voltage
NO LOAD POWER ESTIMATOR					
EFF_NOLOAD			0.60	%/100	Assumed efficiency at no load (0.6 if no better data available)
VAC_INPUT			230	Volts	AC input voltage for no load power estimation
PB_NOLOAD			4.57	mW	Bias winding power consumption estimate at no load
P_PRELOAD			6.84	mW	Preload resistor power consumption at no load
P_STARTUPRES			1.96	mW	Energy dissipated by the startup resistor
C_CLAMP				nF	Clamp capacitor (if clamp capacitor not defined then it will be assumed that clamp dissipation is 10% of estimated switching losses)
C_PARASITIC				pF	Estimated primary side parasitic capacitance. If no value entered the primary resonant frequecy will be used to estimate this parameter assumming LPTYP
PSW			0.22	mW	Power losses of the switch and clamp
P_NOLOAD_TOTAL			21.20	mW	Estimated no load power consumption

Note: The power output of all three outputs has been combined together for the purpose of spreadsheet design.

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8 Transformer Specification

8.1 Electrical Diagram

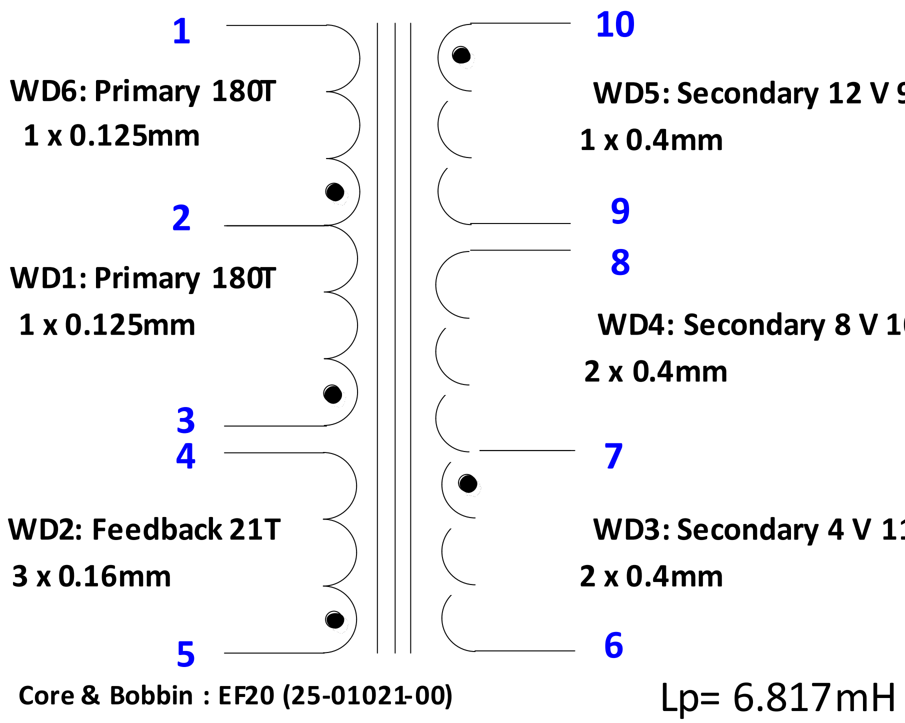

Figure 5 – Transformer Electrical Diagram.

8.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1-5 to FL1/FL2.	3000 VAC
Primary Inductance	Pins 6-5, all others open, measured at 100 kHz, 0.4 V_{RMS}.	6.817 mH ±10%
Resonant Frequency	Pins 6-5 all others open.	400 kHz (Min.)
Primary Leakage	Pins 6-5, with pins FL1/FL2 shorted, measured at 100 KHz, 0.4V_{RMS}.	180 μH (Max.)

8.3 Materials

Item	Description
[1]	Core: EF20; or equivalent, gapped for ALG of 378 nH/t^2.
[2]	Bobbin: EF20 PI part # 25-01021-00; or equivalent.
[3]	Magnet Wire: #37 AWG, solderable double coated.
[4]	Magnet Wire: #34 AWG, solderable double coated.
[5]	Magnet Wire: #26 AWG, solderable double coated.
[6]	Tape, Polyester web, 3M 44 or equivalent, 12.2 mm wide.
[7]	Varnish.

8.4 Transformer Build Diagram

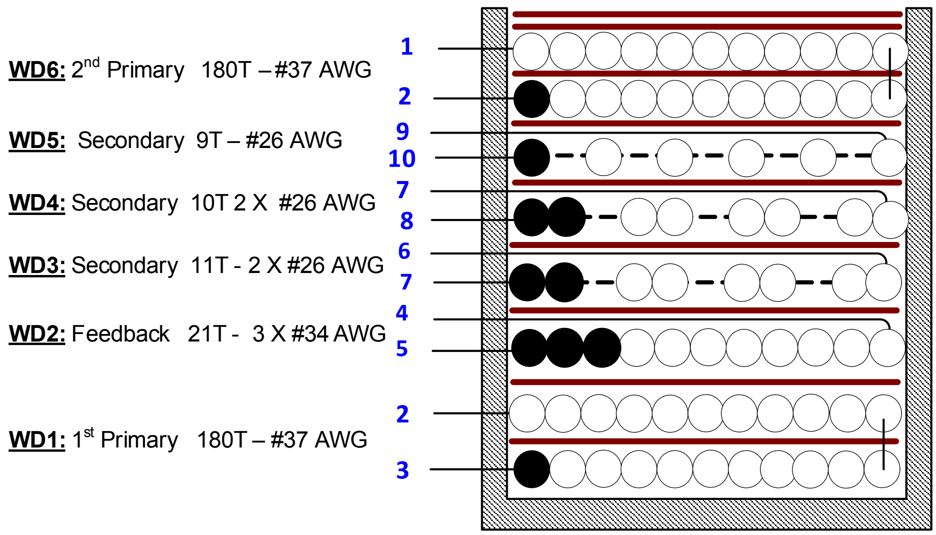

Figure 6 – Transformer Build Diagram.

8.5 Transformer Construction

Bobbin Preparation	For the purpose of these instructions, bobbin is oriented on winder such that pin side is on the left side. Winding direction is clockwise direction.
WD1 1st Primary	Starting at pin 3, wind 180 turns of wire item [3] in 2 layers. Apply 1 layer of tape item [6] in between layers. Finish at pin 2.
Insulation	Use 1 layer of tape item [6] for insulation.
WD2 Feedback	Starting at pin 5, wind 21 trifilar turns of wire item [4] in one layer. Finish at pin 4.
Insulation	Use 1 layer of tape item [6] for insulation.
WD3Secondary	Starting at pin 7, wind 11 bifilar turns of wire item [5] in one layer. Spread the winding evenly across the entire bobbin. Finish at pin 6.
Insulation	Use 1 layer of tape item [6] for insulation.
WD4 Secondary	Starting at pin 8, wind 10 bifilar turns of wire item [5] in one layer. Spread the winding evenly across the entire bobbin. Finish at pin 7.
Insulation	Use 1 layer of tape item [6] for insulation.
WD5 Secondary	Starting at pin 10, wind 9 turns of wire item [5] in one layer. Spread the winding evenly across the entire bobbin. Finish at pin 9.
Insulation	Use 1 layer of tape item [6] for insulation.
WD6 2nd Primary	Starting at pin 2, wind 180 turns of wire item [3] in 2 layers. Apply 1 layer of tape item [6] in between layers. Finish at pin 1.
Insulation	Use 1 layer of tape item [6] for insulation.
Final Assembly	Grind core halves for specified primary inductance. Dip varnish item [7].

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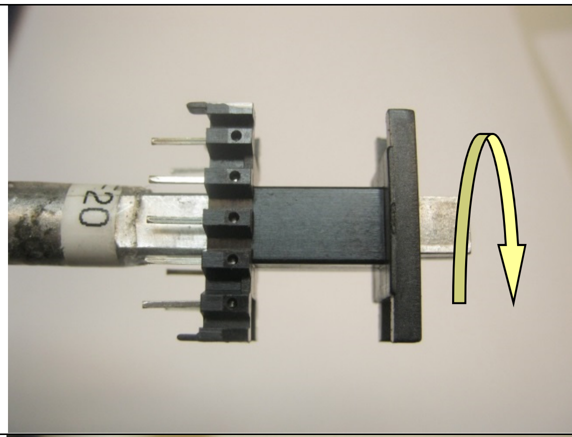
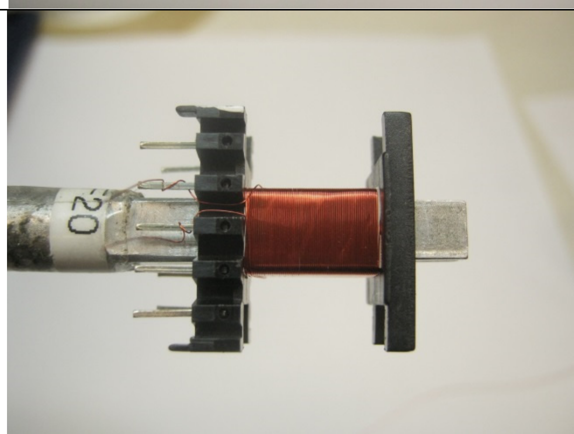
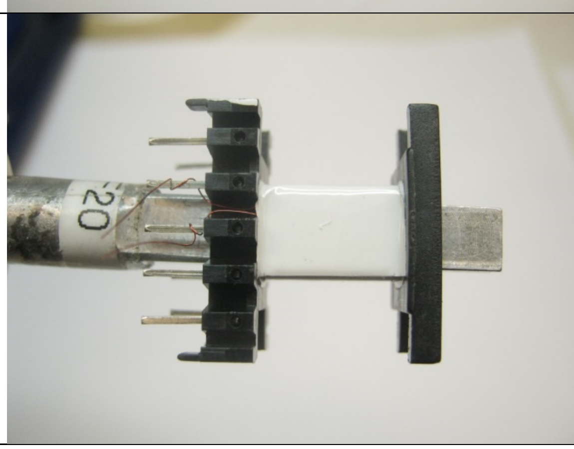
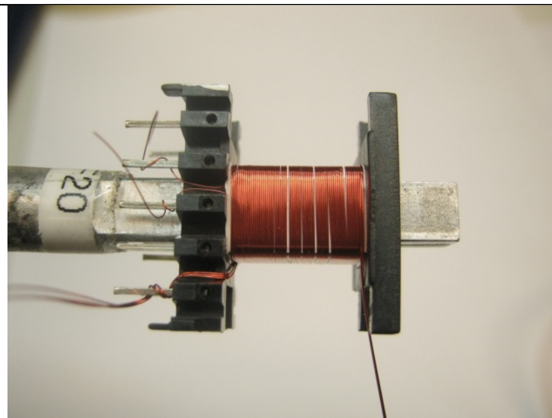
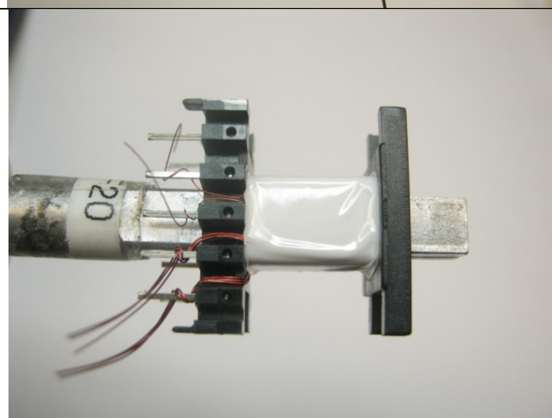
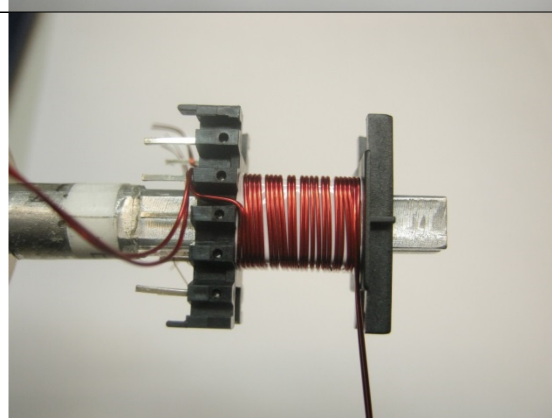
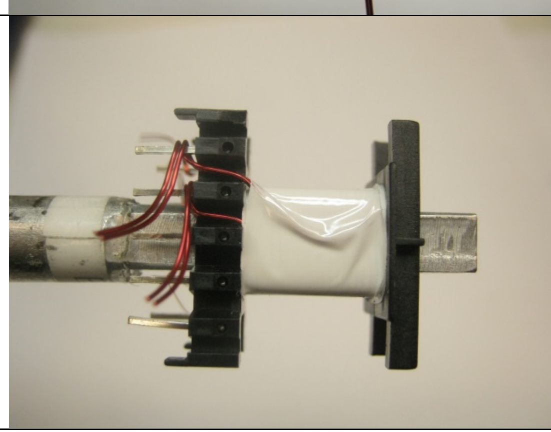
8.6 Transformer Illustrations

General Note		For the purpose of these instructions, bobbin is oriented on winder such that pin side is on the left side. Winding direction is clockwise direction.
WD1		Starting at pin 3, wind 180 turns of wire item [3] in 2 layers. Apply 1 layer of tape item [6] in between layers. Finish at pin 2.
Insulation		Use 1 layer of tape item [6] for insulation.

WD2		Starting at pin 5, wind 21 trifilar turns of wire item [4] in one layer. Finish at pin 4.
Insulation		Use 1 layer of tape item [6] for insulation.
WD3		Starting at pin 7, wind 11 bifilar turns of wire item [5] in one layer. Spread the winding evenly across the entire bobbin. Finish at pin 6.
Insulation		Use 1 layer of tape item [6] for insulation.

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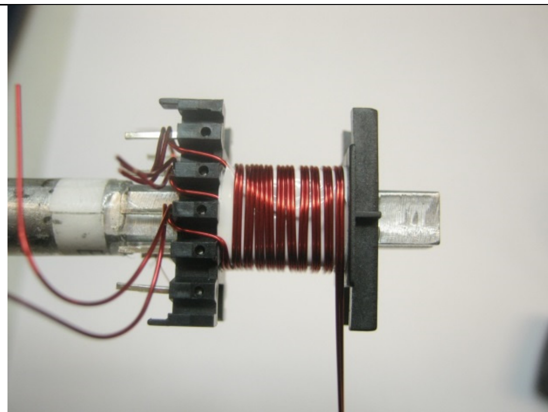
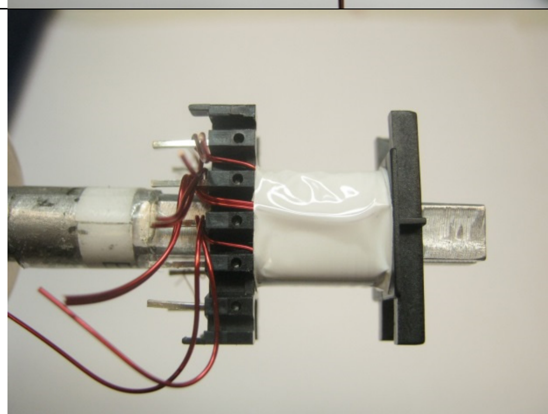
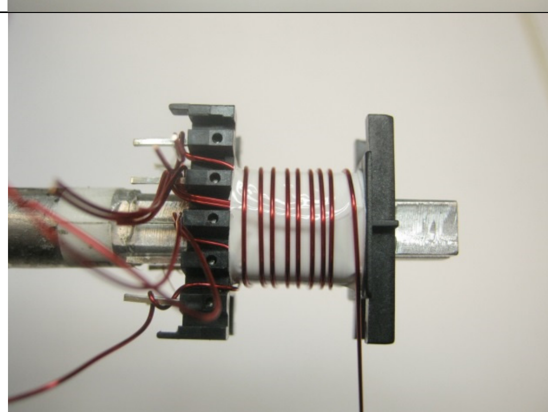
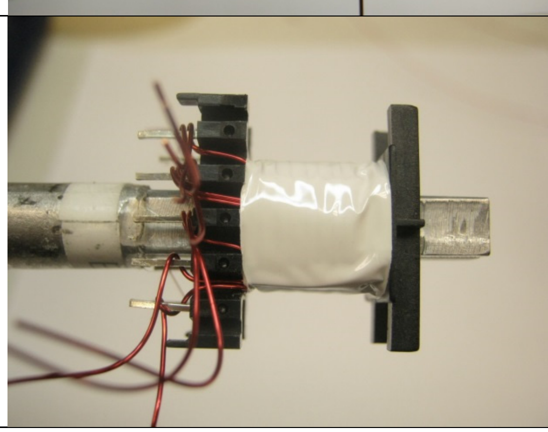
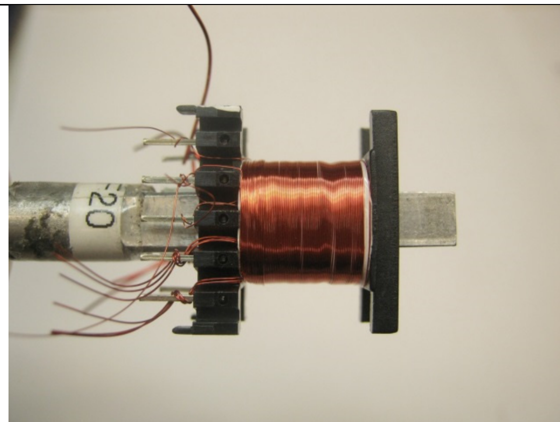
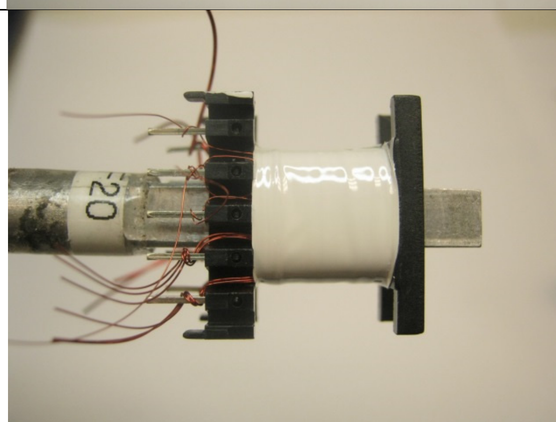
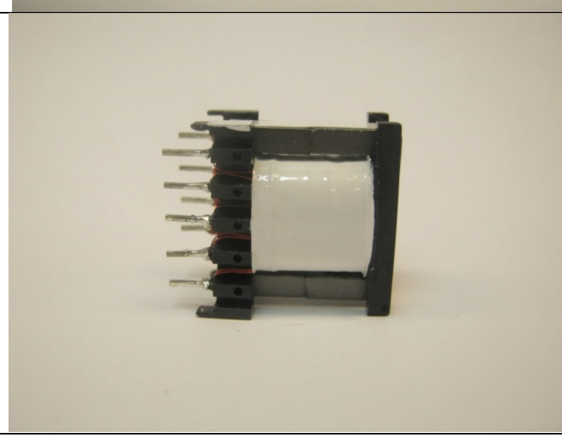
WD4		Starting at pin 8, wind 10 bifilar turns of wire item [5] in one layer. Spread the winding evenly across the entire bobbin. Finish at pin 7.
Insulation		Use 1 layer of tape item [6] for insulation.
WD5		Starting at pin 10, wind 9 turns of wire item [5] in one layer. Spread the winding evenly across the entire bobbin. Finish at pin 7.
Insulation		Use 1 layer of tape item [6] for insulation.

WD6		Starting at pin 2, wind 180 turns of wire item [3] in 2 layers. Apply 1 layer of tape item [6] in between layers. Finish at pin 1.
Insulation		Use 1 layer of tape item [6] for insulation.
Final Assembly		Grind core halves for specified primary inductance. Dip varnish item [7].

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9 Performance Data

All measurements performed at room temperature and V_{IN} = 230 VAC, 50 Hz line frequency unless otherwise specified.

9.1 Efficiency

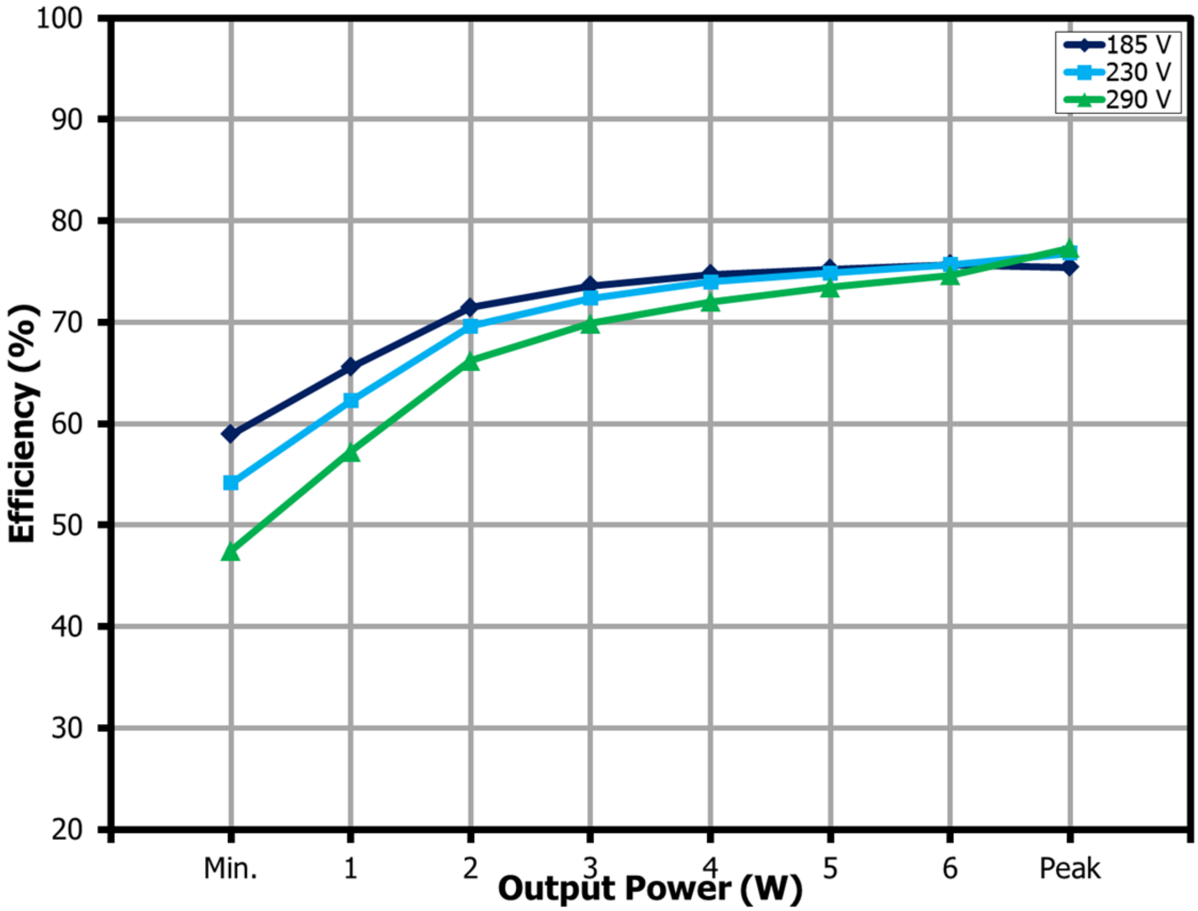

Figure 7 – Efficiency.

9.2 No-Load Input Power

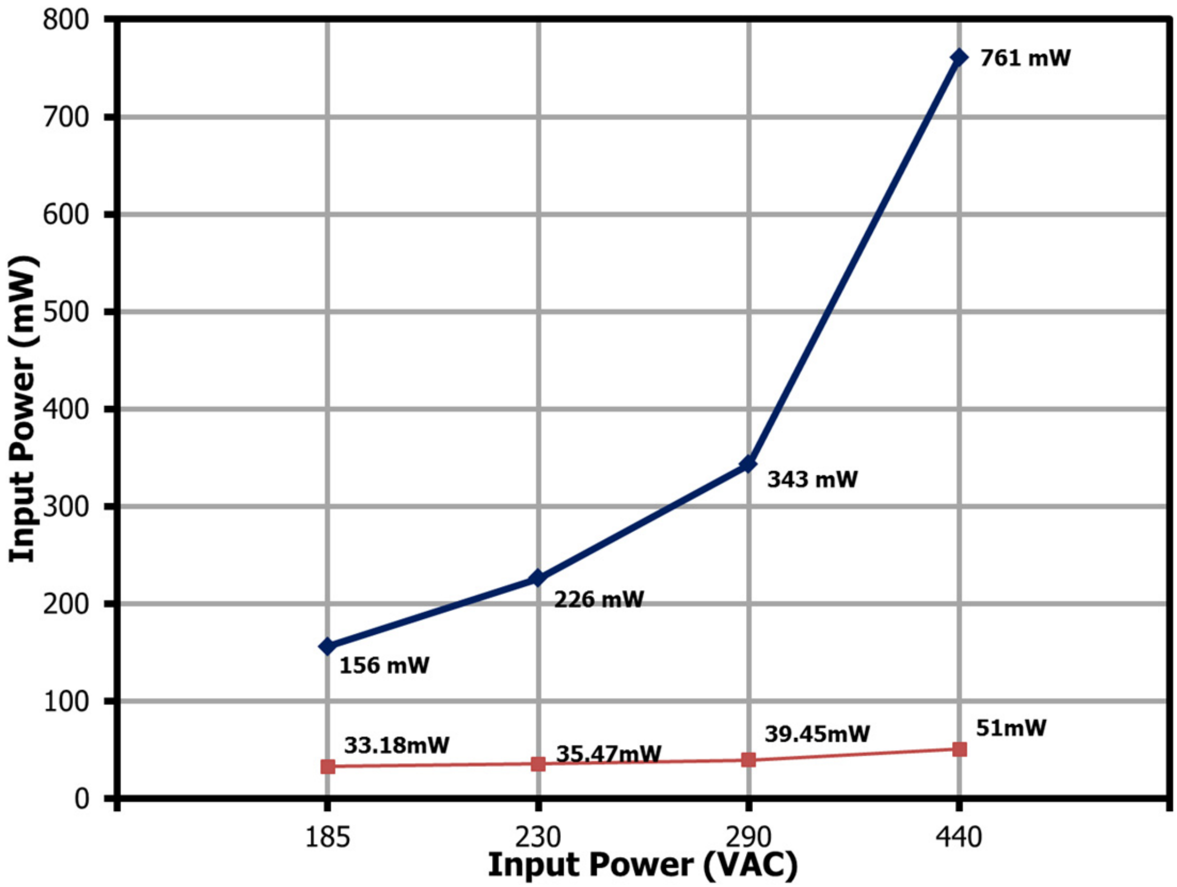

Figure 8 – No-Load Input Power.

Note: Blue colored line is for no-load input power measured with filter capacitor balancing resistors R5, R6, R7 and R8 installed.

The input power for the power supply circuit without the balancing resistors is <50 mW at 230 VAC and is shown in **Red** color.

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9.3 Waveforms

9.3.1 Collector Current and Collector-GND Voltage at Full Load

Figure 9 – 185 VAC, Full Load.
Upper: V_{CE}, 100 V / div.
Lower: I_{CE}, 89 mA/ div., 20 μs / div.

Figure 10 – 230 VAC, Full Load.
Upper: V_{CE}, 100 V / div.
Lower: I_{CE}, 89 mA / div., 20 μs / div.

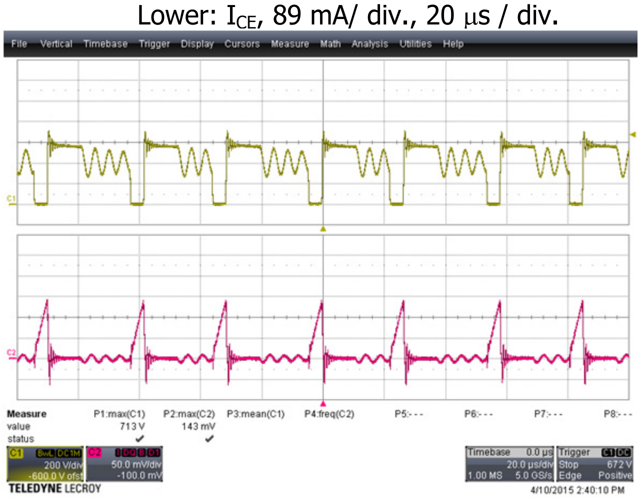

Figure 11 – 290 VAC, Full Load.
Upper: V_{CE}, 200 V / div.
Lower: I_{CE}, 89 mA / div., 20 μs / div.

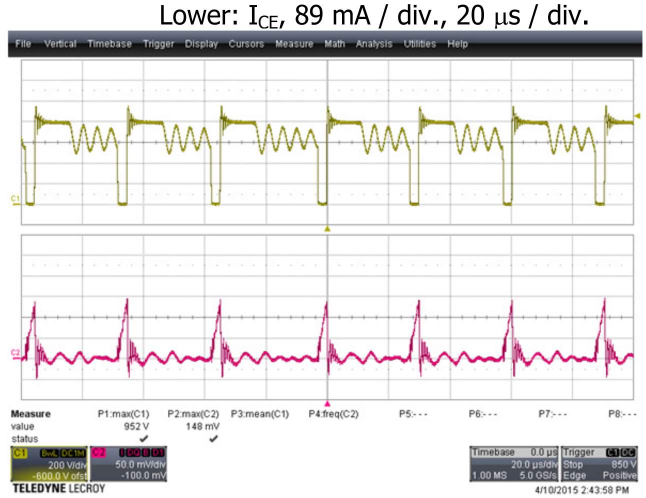

Figure 12 – 622 VDC, Full Load.
Upper: V_{CE}, 200 V / div.
Lower: I_{CE}, 89 mA / div., 20 μs / div.

- Current sense waveforms are measured across the current sense resistor R4 (refer to Figure 3).

9.3.2 Collector Current and Collector-GND Voltage at Peak Load

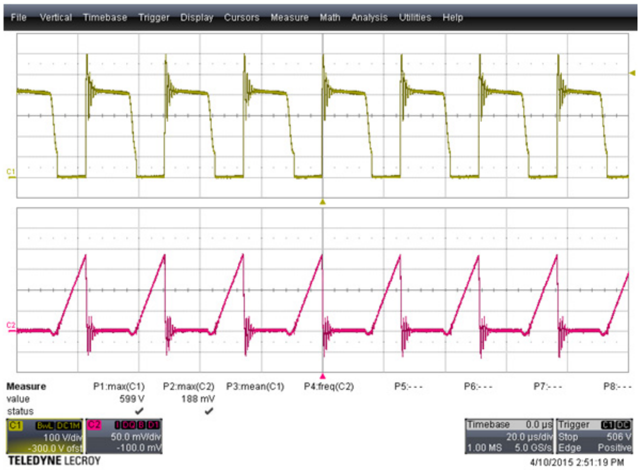

Figure 13 – 185 VAC, Peak Load.
Upper: V_{CE}, 100 V / div.
Lower: I_{CE}, 89 mA / div., 20 µs / div.

Figure 14 – 230 VAC, Peak Load.
Upper: V_{CE}, 100 V / div.
Lower: I_{CE}, 89 mA / div., 20 µs / div.

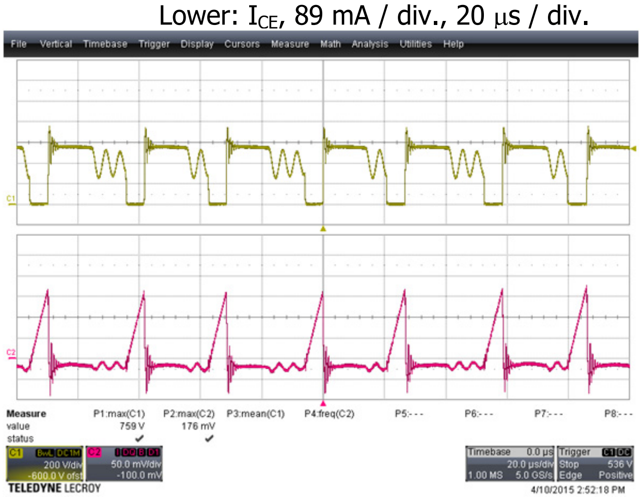

Figure 15 – 290 VAC, Peak Load.
Upper: V_{CE}, 200 V / div.
Lower: $I_{CE,}$ 89 mA / div., 20 µs / div.

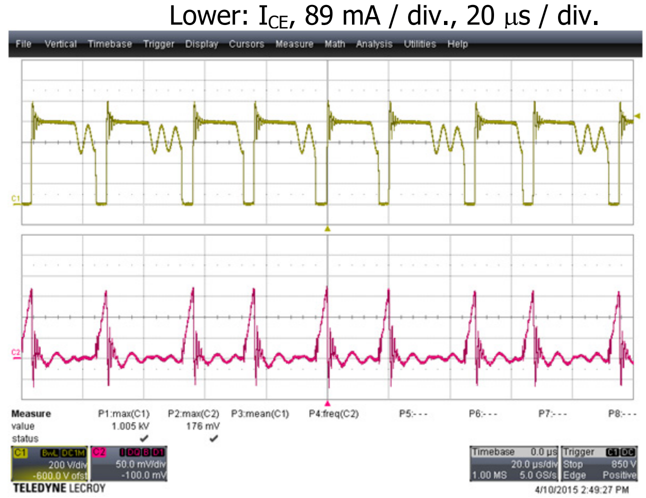

Figure 16 – 622 VDC, Peak Load.
Upper: V_{CE}, 200 V / div.
Lower: I_{CE}, 89 mA / div., 20 µs / div.

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9.3.3 Collector Current and Collector-Emitter Voltage Start-up Waveforms at Full Load

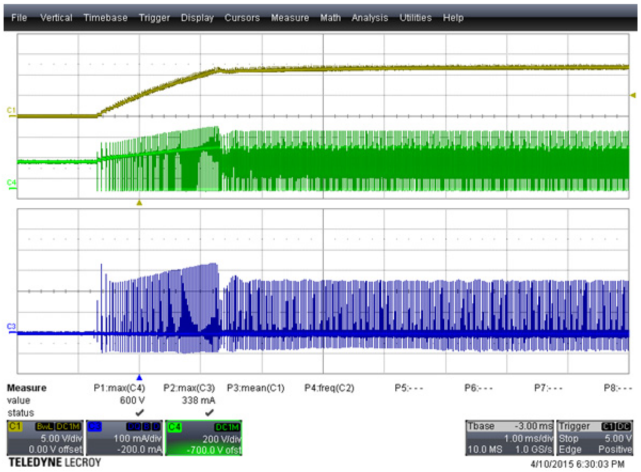

Figure 17 – 185 VAC, Full Load.
C1: V_{OUT} for 12 V, 5 V / div.
C2: V_{CE}, 200 V / div.
C3: I_C, 100 mA / div., 1 ms / div.

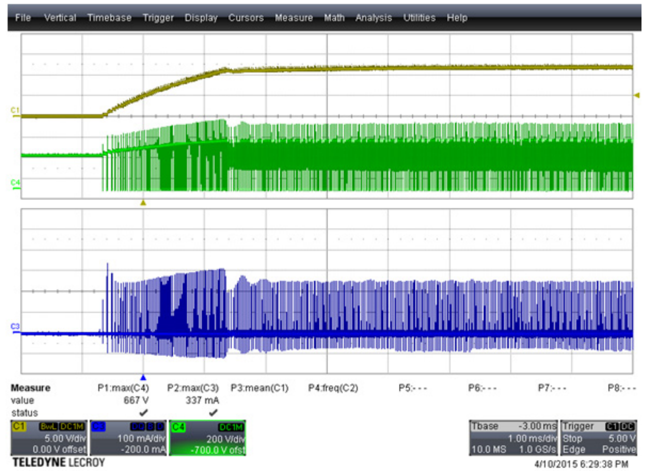

Figure 18 – 230 VAC, Full Load.
C1: V_{OUT} for 12 V.
C2: V_{CE}, 200 V / div.
C3: I_C, 100 mA / div., 1 ms / div.

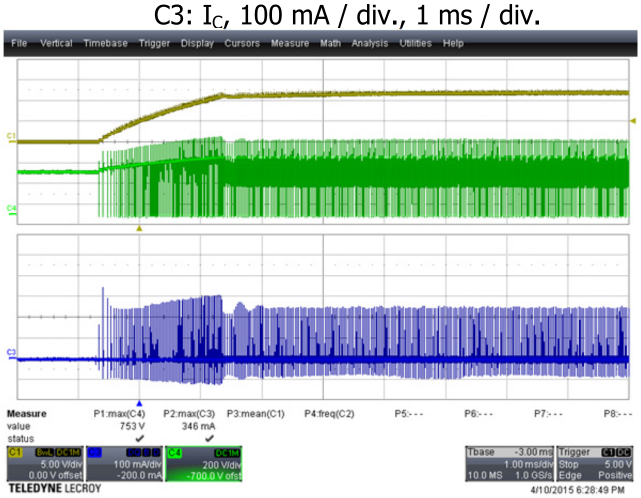

Figure 19 – 290 VAC, Full Load. $V_{CE(MAX)}$ = 753 V.
C1: V_{OUT} for 12 V, 5 V / div.
C2: V_{CE}, 200 V / div.
C3: I_C, 100 mA / div., 1 ms / div.

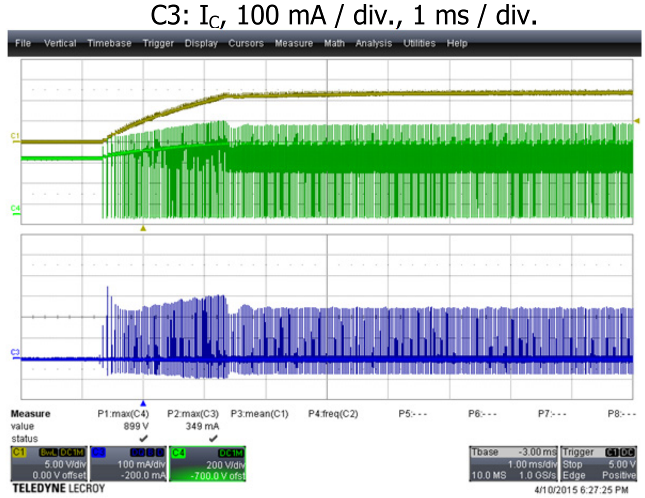

Figure 20 – 622 VDC, Full Load. $V_{CE(MAX)}$ = 899 V.
C1: V_{OUT} for 12 V, 5 V / div.
C2: V_{CE}, 200 V / div.
C3: I_C, 100 mA / div., 1 ms / div.

9.3.4 Diode Peak Inverse Voltage

Figure 21 – 622 VDC, Full Load. $V_{R(MAX)}$ = 24.9 V.
C2: V_{OUT} for 4 V, 5 V / div.

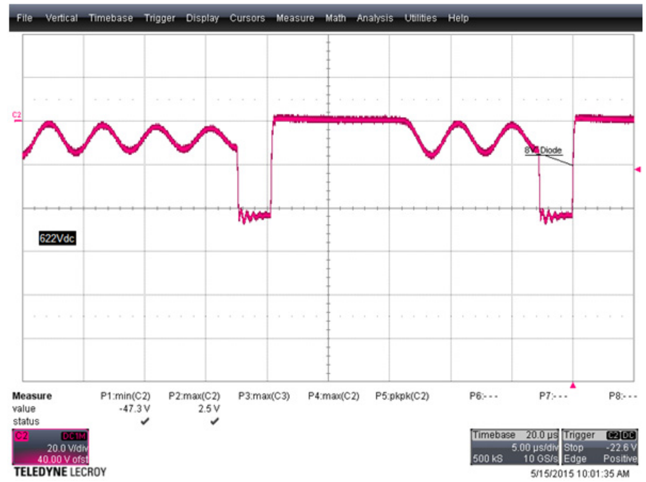

Figure 22 – 622 VDC, Full Load. $V_{R(MAX)}$ = 47.3 V.
C2: V_{OUT} for 8 V, 20 V / div.

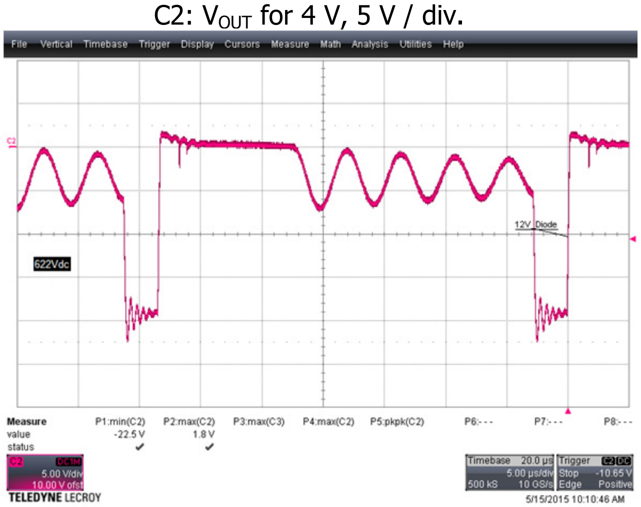

Figure 23 – 622 VDC, Full Load. $V_{R(MAX)}$ = 22.5 V.
C2: V_{OUT} for 12 V, 5 V / div.

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9.4 Output Ripple and Noise Measurements

9.4.1 Ripple Measurement Technique

For DC output ripple measurements, a modified oscilloscope test probe must be utilized in order to reduce spurious signals due to pick-up. Details of the probe modification are provided in the figures below.

The 5125BA probe adapter is affixed with two capacitors tied in parallel across the probe tip. The capacitors include one (1) 0.1 μF / 50 V ceramic type and one (1) 1 μF / 50 V aluminum electrolytic. ***The aluminum electrolytic type capacitor is polarized, so proper polarity across DC outputs must be maintained (see below).***

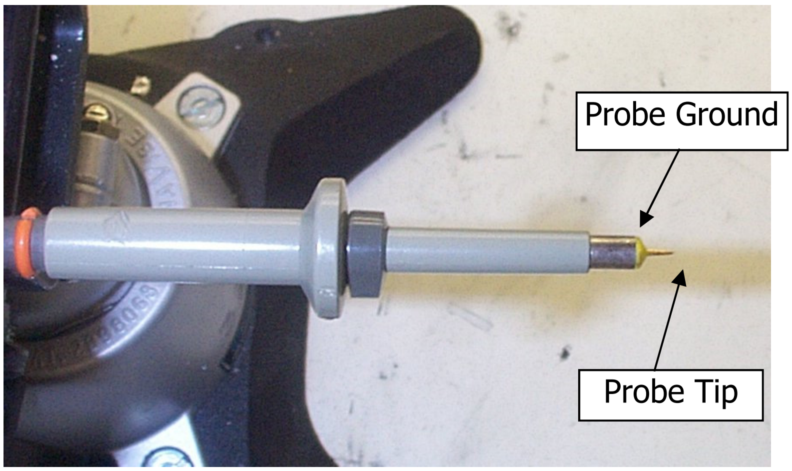

Figure 24 – Oscilloscope Probe Prepared for Ripple Measurement (End Cap and Ground Lead Removed).

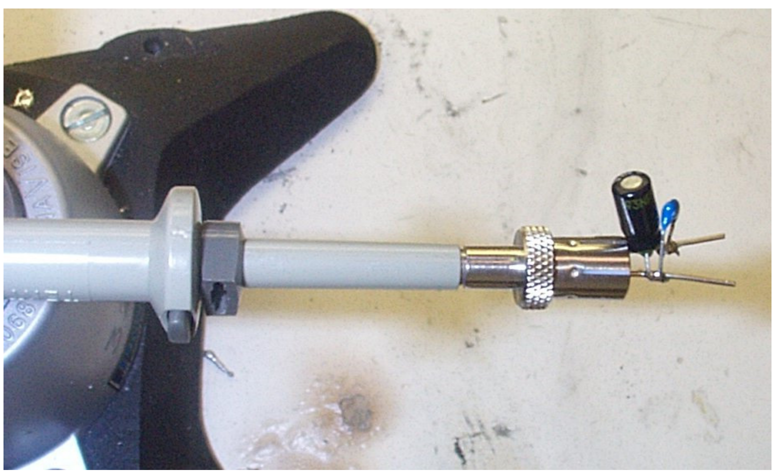

Figure 25 – Oscilloscope Probe with Probe Master 5125BA BNC Adapter (Modified with Wires for Probe Ground for Ripple Measurement, and Two Parallel Decoupling Capacitors Added).

9.4.2 Ripple and Noise Measurement Results

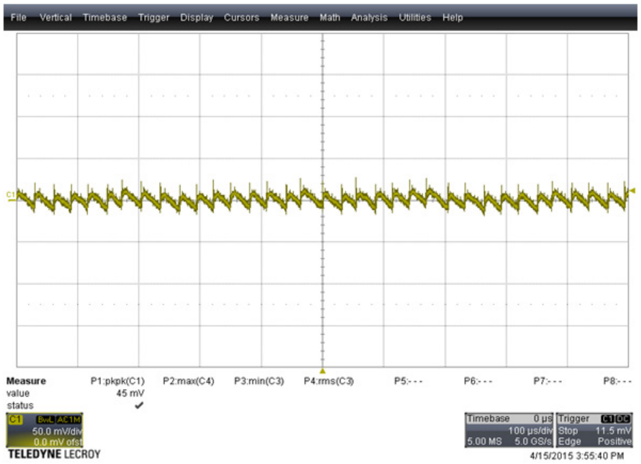

Figure 26 – Low Frequency Ripple, 230 VAC, Full Load. 4 V_{OUT}.

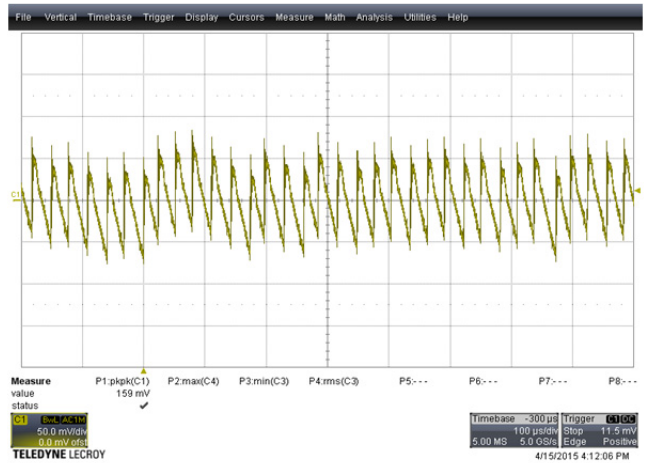

Figure 27 – Low Frequency Ripple, 230 VAC, Full Load. 8 V_{OUT}.

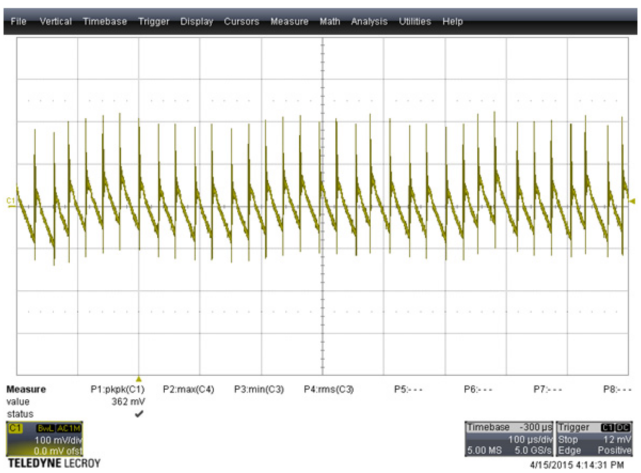

Figure 28 – Low Frequency Ripple, 230 VAC, Full Load. 12 V_{OUT}.

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10 EMI Measurement

All measurements have been done at room temperature.
Note: EMI Measurements have been made with resistors R26, R27 and R28 and capacitor C6 to represent EMI filter used on the meter circuit board.

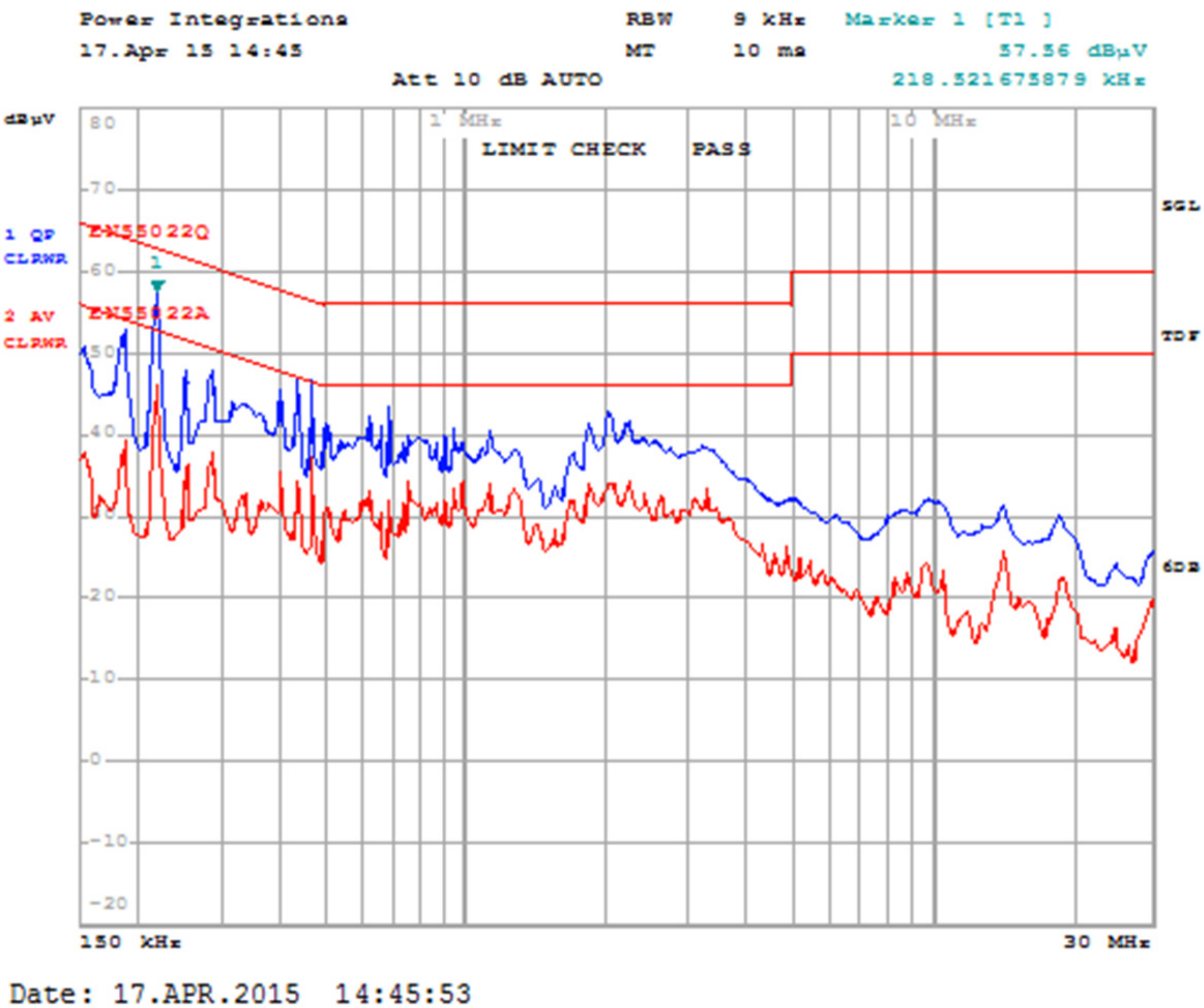

Figure 29 – QP (Blue) and AV (Red), 230 VAC, Full Load. Neutral to GND.

Figure 30 – QP (Blue) and AV (Red), 230 VAC, Full Load. Line to GND.

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11 Thermal Performance

All measurements have been done at room temperature with natural convection after 30 minutes of working cycle.

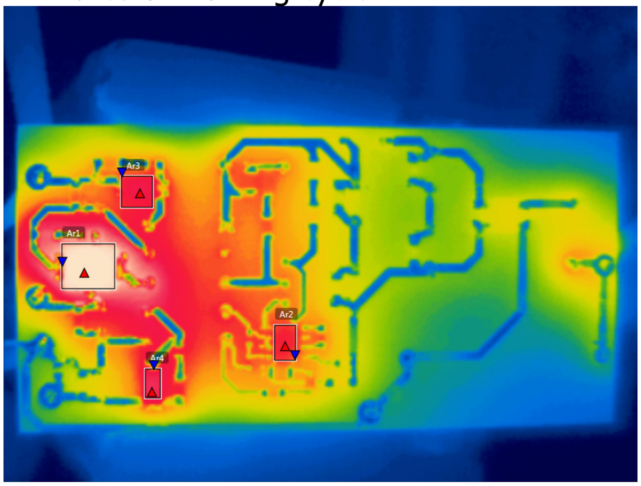

Figure 31 – 185 VAC, Full Load. Bottom Side.
Ambient = 23.8 °C.
Ar1: 8 V Diode D3 = 70.4 °C.
Ar2: LNK4004D U1 = 48.7 °C.
Ar3: 12 V Diode D5 = 51.5 °C.
Ar4: 4 V Diode D4 = 52.9 °C.

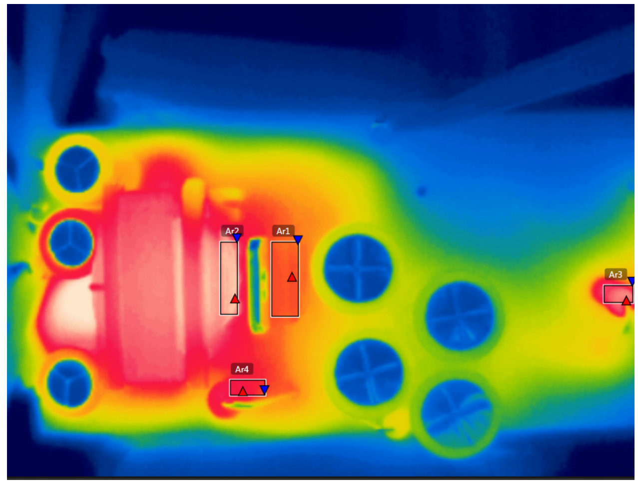

Figure 32 – 185 VAC, Full Load. Top Side.
Ambient = 23.6 °C.
Ar1: BJT Q1 = 45.5 °C.
Ar2: Transformer T1 = 55.6 °C.
Ar3: Primary Snubber Resistor R13 = 52.9 °C.

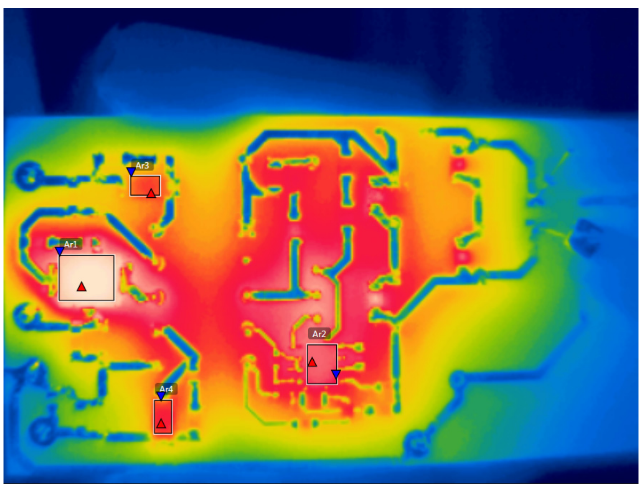

Figure 33 – 622 VDC, Full Load. Bottom Side.
Ambient = 24.3 °C.
Ar1: 8 V Diode D3 = 75.1 °C.
Ar2: LNK4004D U1 = 63.5 °C.
Ar3: 12 V Diode D5 = 56.3 °C.
Ar4: 4 V Diode D4 = 57.6 °C.

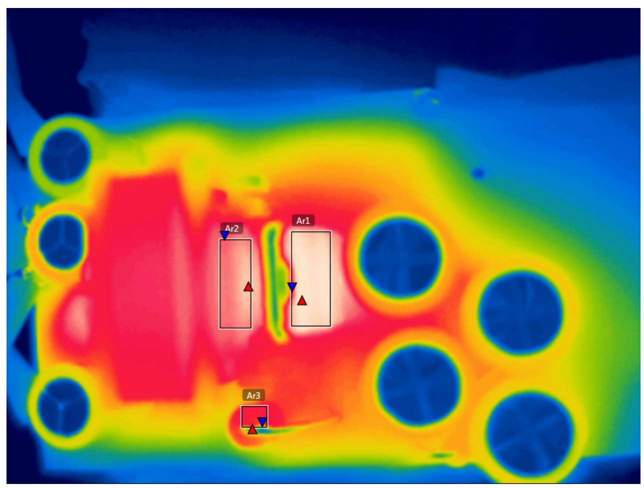

Figure 34 – 622 VDC, Full Load. Top Side.
Ambient = 24.3 °C.
Ar1: BJT Q1 = 69 °C.
Ar2: Transformer T1 = 65.9 °C.
Ar3: Primary Snubber Resistor R13 = 57.3 °C .

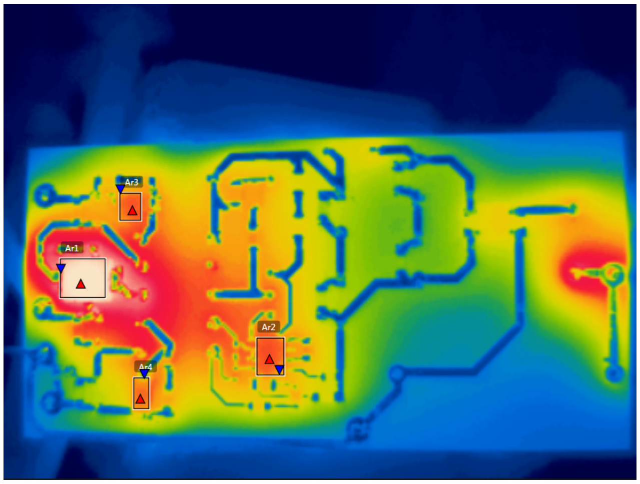

Figure 35 – 185 VAC, Peak Load. Bottom Side.
Ambient = 25.1 °C.
Ar1: 8 V Diode D3 = 112.4 °C.
Ar2: LNK4004D U1 = 70.2 °C.
Ar3: 12 V Diode D5 = 69.2 °C.
Ar4: 4 V Diode D4 = 68.1 °C.

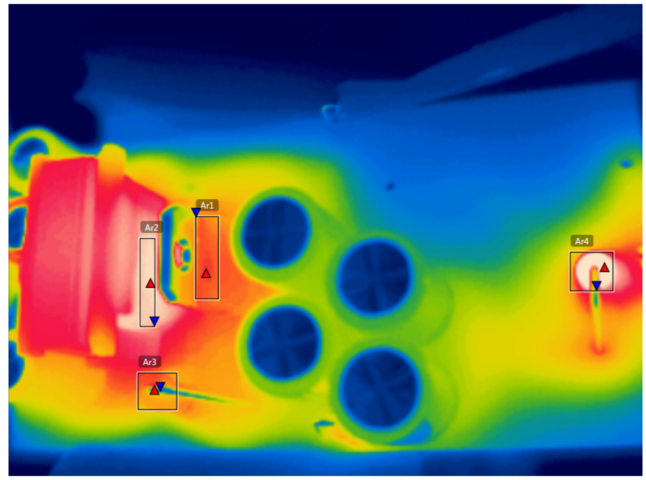

Figure 36 – 185 VAC, Peak Load. Top Side.
Ambient = 24.7 °C.
Ar1: BJT Q1 = 67.6 °C.
Ar2: Transformer T1 = 88.1 °C.
Ar3: Primary Snubber Resistor R13 = 72.6 °C.
Ar4: R9 (Refer to Figure 3) = 106.7 °C.

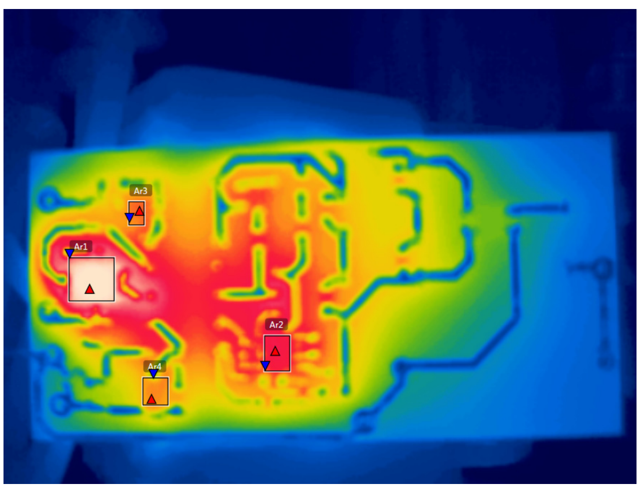

Figure 37 – 622 VDC, Peak Load. Bottom Side
Ambient = 25 °C.
Ar1: 8 V Diode D3 = 114.2 °C.
Ar2: LNK4004D U1 = 80.5 °C.
Ar3: 12 V Diode D5 = 71.8 °C.
Ar4: 4 V Diode D4 = 70.0 °C.

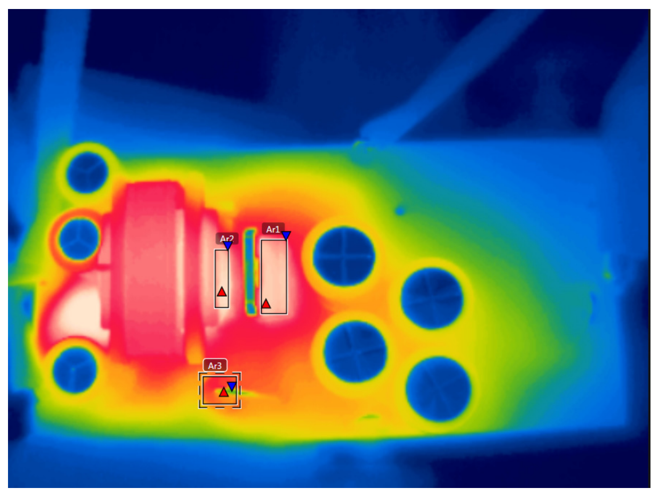

Figure 38 – 622 VDC, Peak Load. Top Side.
Ambient = 25.1 °C.
Ar1: BJT Q1 = 85.4 °C.
Ar2: Transformer T1 = 88.1 °C.
Ar3: Primary Snubber Resistor R13 = 73.3 °C.

Note:

1. The above test data is for peak load condition over a prolonged period of time. In real metering application, the expected duration of peak load condition is < 1s.
2. Continuous operation at 440VAC in an enclosed adapter or housing where ambient temperatures are likely to exceed 45°C may require additional heat sink for some of the components.

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12 Cross Regulation and Efficiency

V_{IN} (V)	P_{IN} (W)	12 V V_{OUT} (V)	Regulation 12 V_{OUT} (%)	12 V I_{OUT} (mA)	8 V V_{OUT} (V)	Regulation 8 V_{OUT} (%)	8 V I_{OUT} (mA)	4 V V_{OUT} (V)	Regulation 4 V_{OUT} (%)	4 V I_{OUT} (mA)	P_{OUT} (W)	Efficiency (%)
185	0.951	11.511	-4.07	**29.06**	8.368	4.60	**21.68**	3.935	-6.31	**10.02**	0.555	58.40
	1.648	12.239	1.99	30.92	8.802	10.03	22.83	3.839	-8.59	117.9	1.032	62.62
	1.971	11.485	-4.29	96	8.394	4.93	21.76	4.022	-4.24	10.27	1.326	67.30
	2.67	11.829	-1.42	**99.3**	8.599	7.49	22.31	3.862	-8.04	118.4	1.824	68.31
	6.146	12.546	4.55	31.68	8.396	4.95	498	4.160	-0.96	10.62	4.623	75.22
	6.792	12.686	5.72	32.05	8.420	5.25	**500**	3.950	-5.95	121.2	5.095	75.02
	7.201	11.854	-1.22	99.6	8.409	5.11	498	4.162	-0.89	10.64	5.413	75.17
	7.857	11.913	-0.73	100.2	8.432	5.39	500	3.963	-5.63	**121.6**	**5.891**	74.98
230	1.041	11.571	-3.57	29.36	8.408	5.10	21.83	3.962	-5.67	10.14	0.563	54.13
	1.735	12.279	2.33	31.07	8.825	10.31	22.9	3.860	-8.10	118.5	1.041	60.00
	2.051	11.484	-4.30	96.2	8.394	4.92	21.77	4.025	-4.16	10.28	1.329	64.79
	2.748	11.838	-1.35	99.4	8.604	7.55	22.33	3.868	-7.91	118.7	1.828	66.52
	6.178	12.668	5.57	32.16	8.417	5.22	500	4.166	-0.80	10.64	4.660	75.44
	6.828	12.802	6.68	32.44	8.439	5.49	501	3.959	-5.74	121.5	5.124	75.05
	7.869	11.959	-0.34	100.6	8.442	5.53	500	3.970	-5.47	122.2	**5.909**	75.10
	7.865	11.960	-0.33	100.1	8.444	5.55	501	3.972	-5.43	122.1	5.913	75.18
	14.521	12.400	3.33	104.3	8.511	6.39	1151	4.255	1.31	10.87	11.136	76.69
	15.121	12.429	3.58	103.4	8.509	6.36	1150	4.057	-3.40	124.7	11.577	76.56
290	1.188	11.540	-3.84	29.28	8.391	4.89	21.8	3.953	-5.89	10.1	0.561	47.20
	1.879	12.249	2.07	31.01	8.815	10.18	22.88	3.852	-8.29	118.2	1.037	55.18
	2.197	11.472	-4.40	95.9	8.387	4.84	21.77	4.023	-4.21	10.28	1.324	60.27
	2.892	11.828	-1.44	99.3	8.600	7.50	22.32	3.865	-7.98	118.5	1.824	63.08
	6.316	12.714	5.95	32.27	8.407	5.08	498	4.166	-0.81	10.66	4.641	73.48
	6.948	12.867	7.22	32.6	8.429	5.36	499	3.954	-5.85	121.3	5.105	73.47
	7.337	11.917	-0.69	99.5	8.421	5.26	499	4.168	-0.77	10.65	5.432	74.04
	7.973	11.984	-0.13	100.6	8.438	5.47	500	3.968	-5.53	121.8	**5.908**	74.10

- Measurement Condition:
  - Min, max, and peak of load. (All three outputs have the combination of min. ,max. and peak load.)
  - Voltage measurement on the board.
  - Peak load condition of 230 V is highlighted in orange.
  - Full load condition of 230 V is in green.

13 Revision History

Date	Author	Revision	Description & Changes	Reviewed
19-May-15	RJ	1.7	Initial Release	Apps & Mktg
19-May-15	RJ	1.8	Updated No Load Input Power and 440V Specification	

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