Demonstration System EPC9111/EPC9112 Quick Start Guide

6.78 MHz, ZVS Class-D Wireless Power System using EPC2014 and EPC2007

EFFICIENT POWER CONVERSION

DESCRIPTION

The EPC9111 / EPC9112 Wireless power demonstration system is a high efficiency, A4WP compliant, Zero Voltage Switching (ZVS), Voltage Mode Class D Wireless Power transfer demonstration system capable of delivering up to 35 W into a DC load while operating at 6.78 MHz (Lowest ISM band). It includes a pre-regulator that limits the output current and voltage and ensures proper operation of the amplifier regardless of coupling and load variations between the source and device. The purpose of this demonstration system is to simplify the evaluation process of the wireless power technology using eGaN® FETs by including all the critical components on a single board that can be easily connected into any existing system.

The EPC9111/ EPC9112 wireless power system comprises three boards (shown in figure 1) namely:

1) A Source Board (Transmitter or Power Amplifier) EPC9506 (as part of the EPC9111 kit) or EPC9507 (as part of the EPC9112 kit)
2) A Class 3 A4WP compliant Source Coil (Transmit Coil)
3) A Category 3 A4WP compliant Device Coil with rectifier and DC smoothing capacitor.

The Source board features the EPC2014 (40 V rated - EPC9506) or EPC2007 (100 V rated – EPC9507) enhancement mode field effect transistor (FET) in a half bridge topology (single ended configuration) or full bridge topology (differential configuration), and includes the gate driver/s and oscillator that ensures operation of the system at 6.78 MHz. The source board can also be operated using an external oscillator.

The source board is equipped with a pre-regulator that limits the current of the supply to the amplifier. As the amplifier draws more current, which can be due to the absence of a device coil, the pre-regulator will reduce the voltage being supplied to the amplifier that will ensure a safe operating point. The pre-regulator also monitors the temperature of the main amplifier FETs and will reduce current if the temperature exceeds 85°C. The pre-regulator can be bypassed to allow testing with custom control hardware. The board further allows easy access to critical measurement nodes that allow accurate power measurement instrumentation hookup. A simplified diagram of the amplifier board is given in Figure 2.

The Source and Device Coils are Alliance for Wireless Power (A4WP) compliant and have been pre-tuned to operate at 6.78 MHz. The source coil is class 3 and the device coil is category 3 compliant.

The device board includes a high frequency schottky diode based full bridge rectifier and output filter to deliver a filtered unregulated DC voltage. The device board comes equipped with two LED's, one green to indicate the power is being received with an output voltage equal or greater than 4 V and a second red LED that indicates that the output voltage has reached the maximum and is above 37 V. The device board can also be configured as a half bridge rectifier that allows for double output voltage operation.

For more information on the EPC2014 or EPC2007 eGaN FET please refer to the datasheet available from EPC at www.epc-co.com. The datasheet should be read in conjunction with this quick start guide.

Table 1: Performance Summary (TA = 25 °C) EPC9506

Symbol	Parameter	Conditions	Min	Max	Units
V_{DD}	Control Supply Input Range		7	12	V
V_{IN}	Bus Input Voltage Range – Pre-Regulator mode		8	32	V
V_{IN}	Bus Input Voltage Range – Bypass mode		0	32	V
V_{OUT}	Switch Node Output Voltage			V_{IN}	V
I_{OUT}	Switch Node Output Current (each)			10*	A
V_{extosc}	External Oscillator input threshold	Input 'Low'	-0.3	0.8	V
		Input 'High'	2.4	5	V
$V_{Pre\_Disable}$	Pre-regulator disable voltage range	Open drain/ collector	-0.3	5.5	V
$I_{Pre\_Disable}$	Pre-regulator disable current	Open drain/ collector	-1	1	mA
$V_{Osc\_Disable}$	Oscillator disable voltage range	Open drain/ collector	-0.3	5	V
$I_{Osc\_Disable}$	Oscillator disable current	Open drain/ collector	-25	25	mA

* Assumes inductive load, maximum current depends on die temperature – actual maximum current with be subject to switching frequency, bus voltage and thermals.

Table 2: Performance Summary (TA = 25 °C) EPC9507

Symbol	Parameter	Conditions	Min	Max	Units
V_{DD}	Control Supply Input Range		7	12	V
V_{IN}	Bus Input Voltage Range – Pre-Regulator mode		8	36	V
V_{IN}	Bus Input Voltage Range – Bypass mode		0	80	V
V_{OUT}	Switch Node Output Voltage			V_{IN}	V
I_{OUT}	Switch Node Output Current (each)			6*	A
V_{extosc}	External Oscillator input threshold	Input 'Low'	-0.3	0.8	V
		Input 'High'	2.4	5	V
$V_{Pre\_Disable}$	Pre-regulator disable voltage range	Open drain/ collector	-0.3	5.5	V
$I_{Pre\_Disable}$	Pre-regulator disable current	Open drain/ collector	-1	1	mA
$V_{Osc\_Disable}$	Oscillator disable voltage range	Open drain/ collector	-0.3	5	V
$I_{Osc\_Disable}$	Oscillator disable current	Open drain/ collector	-25	25	mA

* Assumes inductive load, maximum current depends on die temperature – actual maximum current with be subject to switching frequency, bus voltage and thermals.

Table 3: Performance Summary (TA = 25 °C) Catagory 3 Device Board

Symbol	Parameter	Conditions	Min	Max	Units
V_{OUT}	Output Voltage Range		0	38	V
I_{OUT}	Output Current Range		0	1.5#	A

\# Actual maximum current subject to operating temperature limits

MECHANICAL ASSEMBLY

The assembly of the EPC9111 / EPC9112 Wireless Demonstration kit is simple and shown in Figure 1. The source coil and amplifier have been equipped with reverse polarity SMA connectors. The source coil is simply connected to the amplifier.

The device board does not need to be mechanically attached to the source coil. Provision has been made that allows the device board to be attached at fixed locations to the source board using nylon hardware (part numbers provided in table 6. This allows for repeatable settings and locations for experimentation.

DETAILED DESCRIPTION

The Amplifier Board (EPC9506 / EPC9507)

Figure 2 shows a diagram of the EPC9506 / EPC9507 ZVS class D amplifier with pre-regulator. The pre-regulator is set to a specified current limit (up to 1.5 A) by adjusting P49 and operates from 8 V through 36 V input. The output voltage of the pre-regulator is limited to approximately 2 V below the input voltage. The pre-regulator can be bypassed by moving the jumper (JP60) over from the right 2 pins to the left 2 pins. To measure the current the amplifier is drawing, an ammeter can be inserted in place of the jumper (JP60) in the location based on the operating mode (pre-regulator or bypass).

The amplifier comes with its own oscillator that is pre-programmed to 6.78 MHz ± 678 Hz. It can be disabled by placing a jumper into J70 or can be externally shutdown using an externally controlled open collector / drain transistor on the terminals of J70 (note which is the ground connection). The switch needs to be capable of sinking at least 25 mA. An external oscillator can be used instead of the internal oscillator when connected to J71 (note which is the ground connection) and the jumper (JP70) is moved from the right 2 pins to the left 2 pins.

The pre-regulator can also be disabled in the same manner as the oscillator using J51. The pre-regulator can be bypassed, to increase the operating voltage (with no current or thermal protection) to the amplifier or to use an external regulator, by moving the jumper JP60 from the right 2 pins to the left 2 pins. Jumper JP60 can also be used to connect an ammeter to measure the current drawn by the amplifier (make sure the ammeter connects to the pins that correspond to the mode of operation either bypass or pre-regulator).

Single Ended Operation

The amplifier can be configured for single ended operation where only devices Q1 and Q2 are used. In this mode only L_{ZVS1} and C_{ZVS} are used to establish ZVS operation. If Q11 and Q12 are populated, then the following changes need to be made to the board:

1) Remove R76 and R77.
2) Short out C46 and C47.
3) Short the connection of JMP1 (back side of the board)
4) Remove LZVS12 (if populated)
5) Add LZVS1 (270nH)
6) Check that CZVS1 is populated, if not then install.
7) R74 and R75 may need to be adjusted for the new operating condition to achieve maximum efficiency (see section on ZVS timing adjustment).

ZVS Timing Adjustment

Setting the correct time to establish ZVS transitions is critical to achieving high efficiency with the EPC9506 / EPC9507 amplifier. This can be done by selecting the values for R74 and R75 respectively. This procedure is best performed using potentiometer P74 and P75 installed that is used to determine the fixed resistor values. The procedure is the same for both single ended and differential mode of operation. The timing MUST initial be set WITHOUT the source coil connected to the amplifier. The timing diagrams are given in Figure 9 and should be referenced when following this procedure. Only perform these steps if changes have been made to the board as it is shipped preset. The steps are:

1. With power off, connect the main input power supply bus to $+V_{IN}$ (J50). Note the polarity of the supply connector.
2. With power off, connect the control input power supply bus to $+V_{DD}$ (J90). Note the polarity of the supply connector.
3. Connect a LOW capacitance oscilloscope probe to the probe-hole J2 and lean against the ground post as shown in Figure 8.
4. Turn on the control supply – make sure the supply is between 7 V and 12 V range (7.5 V is recommended).
5. Turn on the main supply voltage to the required predominant operating value (such as 24 V but NEVER exceed the absolute maximum voltage of 32 V – EPC9506 or 36V - EPC9507).
6. While observing the oscilloscope adjust P74 for the rising edge of the waveform so achieve the green waveform of figure 9. Repeat for the falling edge of the waveform by adjusting P75.
7. Check that the setting remains optimal with a source coil attached. In this case it is important that the source coil is TUNED to resonance WITH an applicable load. Theoretically the settings should remain unchanged. Adjust if necessary.
8. Replace the potentiometers with fixed value resistors.

Differential Operation

The amplifier can be configured for differential operation where all the devices are used; Q1, Q2, Q11 and Q12. In this mode either L_{ZVS1}, L_{ZVS11} and C_{ZVS} or L_{ZVS12} only is used to establish ZVS operation.

Determining Component Values for L_{ZVS}

The ZVS tank circuit is not operated at resonance, and only provides the necessary negative device current for self-commutation of the output voltage at turn off. The capacitance C_{ZVS} is chosen to have a very small ripple voltage component and is typically around 1 µF. The amplifier supply voltage, switch-node transition time will determine the value of inductance for L_{ZVSx} which needs to be sufficient to maintain ZVS operation over the DC device load resistance range and coupling between the device and source coil range and can be calculated using the following equation:

$$L_{ZVS} = \frac{\Delta t_{vt}}{8 \cdot f_{sw} \cdot C_{OSSQ}} \qquad (1)$$

Where:

Δt_{vt} = Voltage transition time [s]

fsw = Operating frequency [Hz]

C_{OSSQ} = Charge equivalent device output capacitance [F].

Note that the amplifier supply voltage V_{AMP} is absent from the equation as it is accounted for by the voltage transition time. The charge equivalent capacitance can be determined using the following equation:

$$C_{OSSQ} = \frac{1}{V_{AMP}} \cdot \int_0^{V_{AMP}} C_{OSS}(v) \cdot dv \qquad (2)$$

To add additional immunity margin for shifts in coil impedance, the value of L_{ZVS} can be decreased to increase the current at turn off of the devices (which will increase device losses). Typical voltage transition times range from 2 ns through 12 ns. For the differential case the voltage and charge (C_{OSSQ}) are doubled.

The Source Coil

Figure 3 shows the schematic for the source coil which is class 3 A4WP compliant. The matching network includes both series and shunt tuning. The matching network series tuning is differential to allow balanced connection and voltage reduction for the capacitors.

The Device Board

Figure 4 shows the basic schematic for the device coil which is category 3 A4WP compliant. The matching network includes both series and shunt tuning. The matching network series tuning is differential to allow balanced connection and voltage reduction for the capacitors. The coil can be configured to used either a half bridge rectifier (by adding a jumper to the coil at the bottom left of the board) or full bridge rectifier.

The device board comes equipped with a kelvin connected output DC voltage measurement terminal and a built in shunt to measure the output DC current.

Two LEDs have been provided to indicate that the board is receiving power with an output voltage greater than 4 V (green LED) and that the board output voltage limit has been reached (greater than 37 V using the red LED).

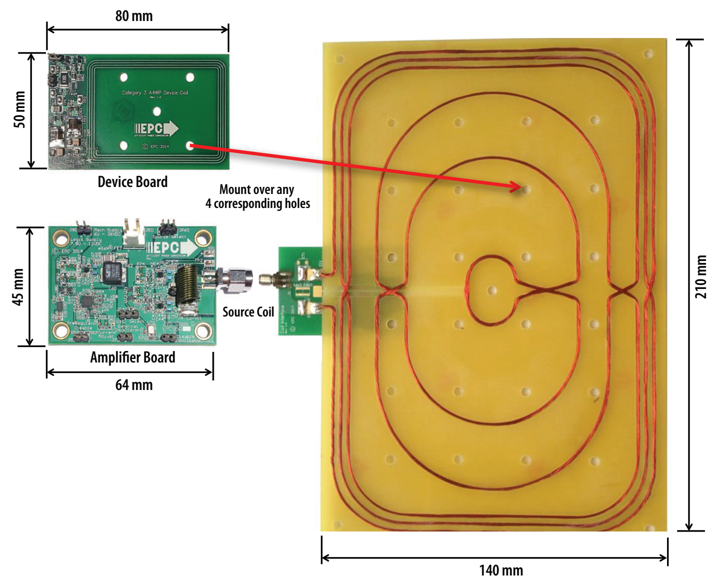

Figure 1: Mechanical Assembly of the EPC9111/ EPC9112 Wireless Energy Transfer Demonstration System

QUICK START PROCEDURE

The EPC9111/ EPC9112 demonstration system is easy to set up and evaluate the performance of the eGaN FET in a wireless power transfer application. Refer to Figure 1 to assemble the system and Figures 4 though Figure 8 for proper connection and measurement setup before follow the testing procedures.

The EPC9111/ EPC9112 can be operated using any one of two alternative methods:

a. Using the pre-regulator
b. Bypassing the pre-regulator

a. Operation using the pre-regulator

The pre-regulator is used to supply power to the amplifier in this mode and will limit the current based on the setting. The pre-regulator also monitors the temperature of the amplifier and will limit the current in the event the temperature exceeds 85°C.

1. Make sure the entire system is fully assembled prior to making electrical connections and make sure jumper (JP60 is set to pre-regulator – right 2 pins).
2. With power off, connect the main input power supply bus to $+V_{IN}$ (J50). Note the polarity of the supply connector.
3. With power off, connect the control input power supply bus to $+V_{DD}$ (J90). Note the polarity of the supply connector.
4. Select and connect an applicable load resistance to the device board.
5. Make sure all instrumentation is connected to the system.
6. Turn on the control supply – make sure the supply is between 7 V and 12 V (7.5 V is recommended).
7. Turn on the main supply voltage to the required value (it is recommended to start at 8 V and do not exceed the absolute maximum voltage of 32 V - EPC9506 or 36 V - EPC9507).
8. Once operation has been confirmed, adjust the main supply voltage within the operating range and observe the output voltage, efficiency and other parameters on both the amplifier and device boards.
9. For shutdown, please follow steps in the reverse order. Start by reducing the main supply voltage to 0 V followed by steps 6 through 2.

b. Operation bypassing the pre-regulator

In this mode, the pre-regulator is bypassed and the main power is connected directly to the amplifier. This allows the amplifier to be operated using an external regulator or to test at higher voltages.

In this mode there is no current or thermal protection for the eGaN FETs.

1. Make sure the entire system is fully assembled prior to making electrical connections and remove the jumper JP60. Never connect the main power positive (+) to J50 when operating in bypass mode.
2. With power off, connect the main input power supply ground to the ground terminal of J50 (-) and the positive (+) to the **center** pin of JP60.
3. With power off, connect the control input power supply bus to $+V_{DD}$ (J90). Note the polarity of the supply connector.
4. Select and connect an applicable load resistance to the device board.
5. Make sure all instrumentation is connected to the system.
6. Turn on the control supply – make sure the supply is between 7 V and 12 V range (7.5 V is recommended).
7. Turn on the main supply voltage to the required value (it is recommended to start at 2 V and do not exceed the absolute maximum voltage of 32 V - EPC9506 or 80 V - EPC9507).
8. Once operation has been confirmed, adjust the main supply voltage within the operating range and observe the output voltage, efficiencyandotherparametersonboththeamplifieranddeviceboards. See Pre-Cautions when operating in the bypass mode
9. For shutdown, please follow steps in the reverse order. Start by reducing the main supply voltage to 0 V followed by steps 6 through 2.

NOTE. When measuring the high frequency content switch-node (Source Coil Voltage), care must be taken to avoid long ground leads. An oscilloscope probe connection (preferred method) has been built into the board to simplify the measurement of the Source Coil Voltage (J2 and J3 as shown in Figure 8).

THERMAL CONSIDERATIONS

The EPC9111/ EPC9112 demonstration system showcases the EPC2014 or EPC2007 eGaN FET in a wireless energy transfer application. Although the electrical performance surpasses that of traditional silicon devices, their relatively smaller size does magnify the thermal management requirements. The EPC9111/EPC9112 is intended for bench evaluation with room ambient temperature with load power up to 35 W without the need for a heat-sink. However, the operator must observe the temperature of the gate driver and eGaN FETs to ensure that both are operating within the thermal limits as per the datasheets.

NOTE. The EPC9111/ EPC9112 demonstration system has limited current and thermal protection only when operating off the Pre-Regulator. When bypassing the pre-regulator there is no current or thermal protection on board and care must be exercised not to over-current or over-temperature the devices. Wide coil coupling and load range variations can lead to increased losses in the devices.

Pre-Cautions

The EPC9111/EPC9112 demonstration system has no controller or enhanced protections systems and therefore should be operated with caution. Some specific pre-cautions are:

1. Never operate the Source Coil within 6 inches in any direction of any solid metal objects as this will shift the tuning of the coil. Please contact EPC should the tuning of the coil be required to change to suit specific conditions so that it can be correctly adjusted for use with the ZVS Class-D amplifer.
2. There is no heat-sink on the devices and during experimental evaluation it is possible present conditions to the amplifier that may cause the devices to overheat. Always check operating conditions and monitor the temperature of the EPC devices using an IR camera.

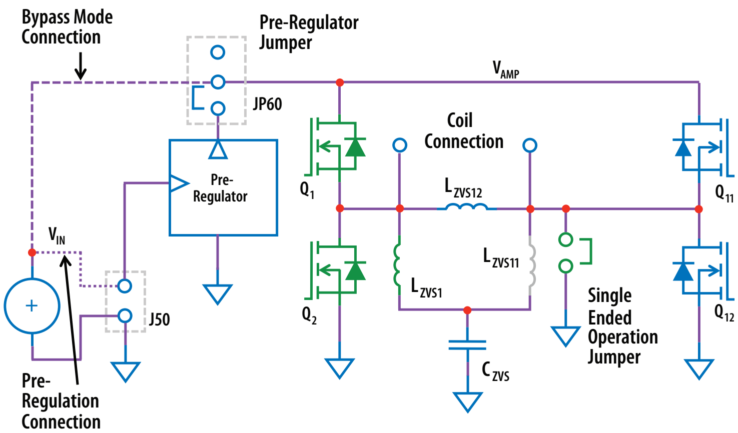

Figure 2: Diagram of EPC9111/ EPC9112 Amplifier Board

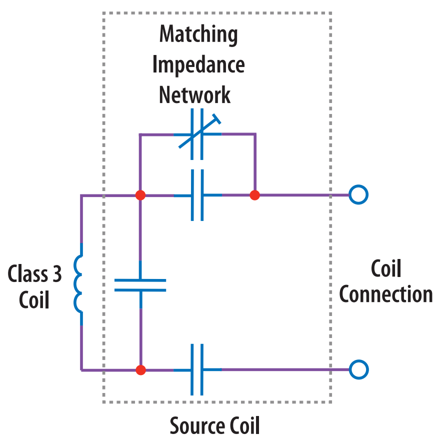

Figure 3: Diagram of the A4WP Class 3 Source Coil

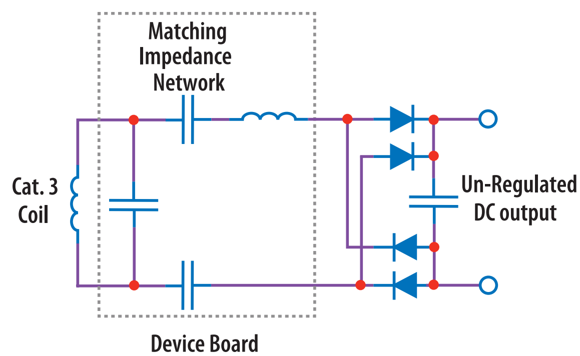

Figure 4: Basic Schematic of the A4WP Category 3 Device Board

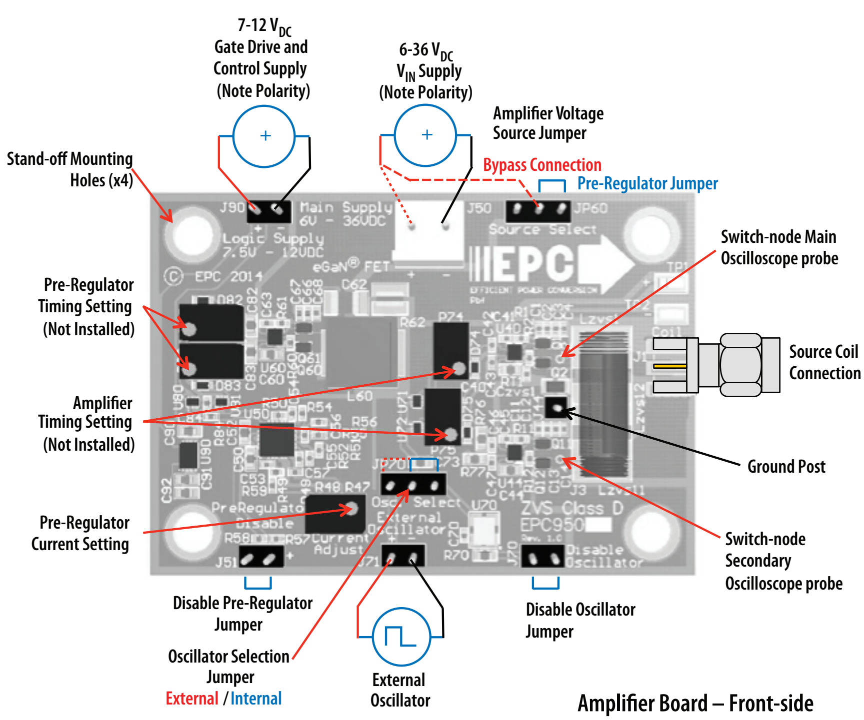

Figure 5: Proper Connection and Measurement Setup for the Amplifier Board

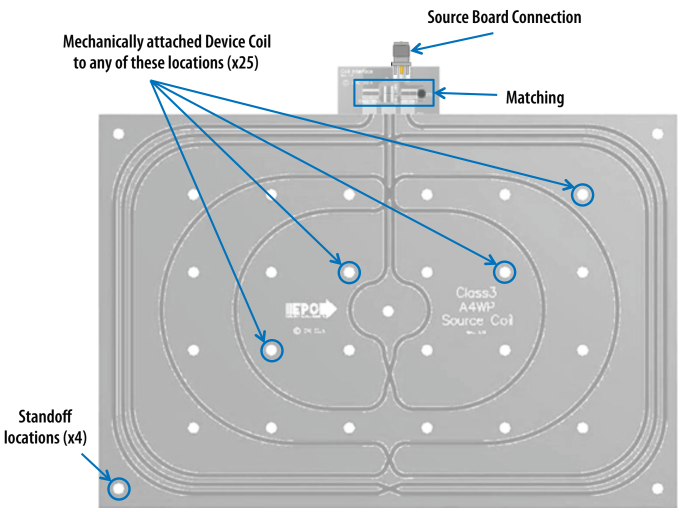

Figure 6: Proper Connection for the Source Coil

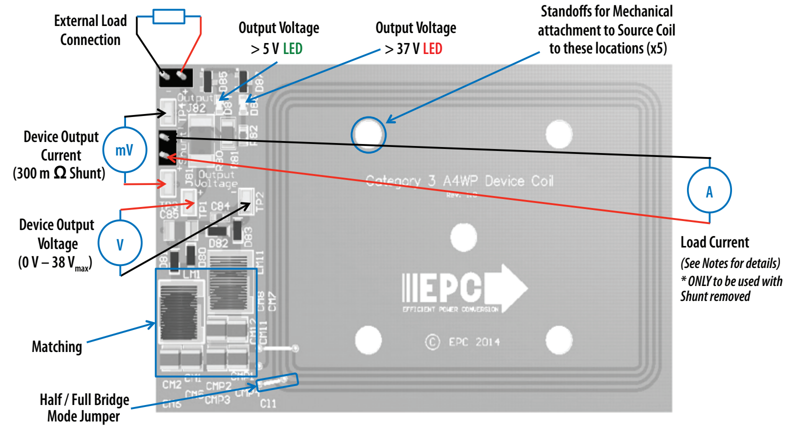

Figure 7: Proper Connection and Measurement Setup for the Device Board

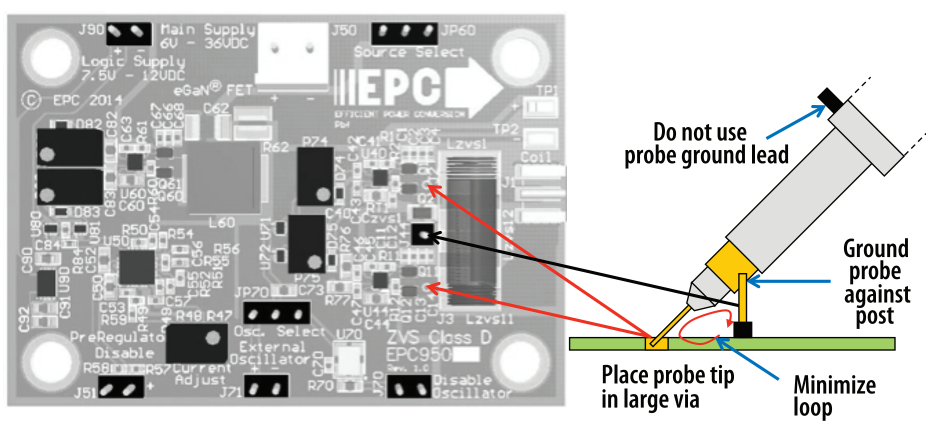

Figure 8: Proper Measurement of the Switch Nodes Using the Hole and Ground Post

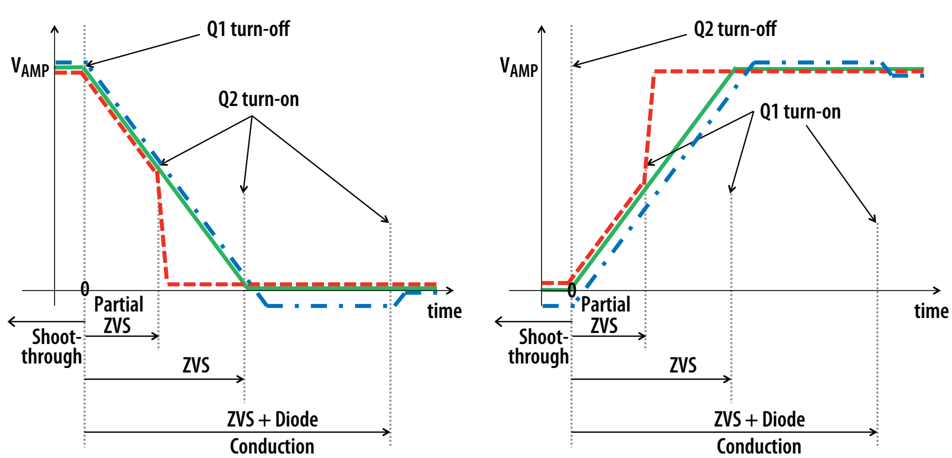

Figure 9: ZVS Timing Diagrams

Table 4 : Bill of Materials - Amplifier Board

Item	Qty	Reference	PartDescription	Manufacturer	Part #
1	12	C1, C2, C3, C4, C11, C12, C13, C14 C55, C66, C67, C68	10nF, 100V	TDK	C1005X7S2A103K050BB
2	7	C5, C6, C15, C16, C62, C64, C65	4.7µF, 50V (EPC9506) 2.2µF, 100V (EPC9507)	Taiyo Yuden	UMK325BJ475MM-T HMK325B7225KN-T
3	4	C40, C44 C52, C60	4.7µF, 16V	TDK	C1608X5R1C475K
4	2	C41, C45	22nF, 25V	TDK	C1005X7R1E223K050BB
5	5	C42, C43, C46, C47 C84	47pF, 50V	Yageo	CC0402JRNPO9BN470
6	1	C50	1µF, 50V	Taiyo Yuden	UMK107AB7105KA-T
7	2	C53, C54	2.2nF, 50V	Yageo	CC0402KRX7R9BB222
8	1	C56	1nF, 50V	Yageo	CC0402KRX7R9BB102
9	3	C57, C63, C70	100nF, 25V	TDK	C1005X7R1E104K050BB
10	4	C71, C72, C80, C81	100nF, 25V	TDK	C1608X7R1E104K
11	1	C73	DNP, 100pF, 25V	Generic	Generic
12	2	C82, C83	100pF, 25V	TDK	C1608C0G1H101J080AA
13	3	C90, C91, C92	1µF, 25V	TDK	C1608X7R1E105K
14	1	Czvs1	DNP 1µF, 50V	Taiyo Yuden	C2012X7R1H105K125AB
15	4	D74, D75, D82, D83	40V, 30mA	Diodes Inc.	SDM03U40
16	1	J1	SMA Board Edge	Linx	CONREVSMA013.062
17	2	J44, J61	.1" Male Vert.	Würth	61300311121
18	1	J50	.156" Male Vert.	Würth	645002114822
19	4	J51, J70, J71, J90	.1" Male Vert.	Würth	61300311121
20	1	JMP1	DNP	–	–
21	2	JP60, JP70	.1" Male Vert.	Würth	61300311121
22	1	L60	10µH	Würth	744314101
23	2	Lzvs1, Lzvs11	DNP, 270nH	CoilCraft	2222SQ-271JEB
24	1	Lzvs12	500nH	CoilCraft	2929SQ-501JEB
25	1	P49	DNP, 10k	Murata	PV37Y103C01B00
26	4	P74, P75, P82, P83	DNP, 1k	Murata	PV37Y102C01B00
27	6	Q1, Q2, Q11, Q12, Q60, Q61	40V, 10A, 16mΩ (EPC9506) 100V, 6A, 30mΩ (EPC9507)	EPC	EPC2014 EPC2007
28	6	R1, R2, R11, R12, R60, R61	2Ω2	Yageo	RC0402JR-072R2L
29	1	R47	6.04k	Panasonic	ERJ-2RKF6041X
30	1	R48	2.74k	Panasonic	ERJ-2RKF2741X
31	1	R49	3.3k	Panasonic	ERJ-2RKF3301X
32	1	R50	40.2k	Yageo	RC0402FR-0740K2L
33	1	R51	280k	Panasonic	ERJ-2RKF2803X
34	1	R52	10k	Yageo	RC0402FR-0710KL
35	1	R54	15k	Yageo	RC0402JR-0715KL
36	3	R55, R56, R84	10Ω	Yageo	RC0402FR-0710RL
37	1	R57	374k	Panasonic	ERJ-2RKF3743X
38	1	R58	124k	Panasonic	ERJ-2RKF1243X
39	1	R59	45.3k	Panasonic	ERJ-2RKF4532X
40	1	R62	24mΩ 1W	Susumu	PRL1632-R024-F-T1
41	1	R70	47k	Stackpole	RMCF0603JT47K0
42	1	R73	10k	Yageo	RC0603JR-0710KL
43	1	R74	82Ω (EPC9506)/ 93.1Ω (EPC9507)	Panasonic	ERJ-3EKF82R0V, ERJ-3EKF93R1V
44	1	R75	124Ω (EPC9506)/133Ω (EPC9507)	Panasonic	ERJ-3EKF1240V, ERJ-3EKF1330V
45	2	R76, R77	0Ω	Yageo	RC0603JR-070RL
46	1	R82	31.6Ω	Panasonic	ERJ-3EKF31R6V
47	1	R83	191Ω	Panasonic	ERJ-3EKF1910V
48	1	RT1	470k at 25°C	Murata	NCP15WM474E03RC

(continued on next page)

Table 4 : Bill of Materials - Amplifier Board (continued)					
Item	**Qty**	**Reference**	**Part Description**	**Manufacturer**	**Part #**
49	2	TP1, TP2	SMD probe loop	Keystone	5015
50	3	U40, U44, U60	100V eGaN Driver	Texas Instruments	LM5113TM
51	1	U50	Step Down Controller	Linear Technologies	LT3741EUF#PBF
52	1	U70	Programmable Oscillator – 6.78MHz	EPSON	SG-8002CE
53	2	U71, U80	2 In AND	Fairchild	NC7SZ08L6X
54	2	U72, U81	2 In NAND	Fairchild	NC7SZ00L6X
55	1	U90	5.0V, 250mA, DFN	Microchip	MCP1703T-5002E/MC
56	2	JPR1 (JP60 right), JPR2 (JP70 right)	.1"jumper	TE Connectivity	382811-8

Table 5: Bill of Materials - Source Coil					
Item	**Qty**	**Reference**	**Part Description**	**Manufacturer**	**Part #**
1	1	CM11	680pF, 300V	Vishay	VJ1111D681KXDAR
2	1	CM1	560pF, 300V	Vishay	VJ1111D561KXDAR
3	1	CM2	27pF, 1500V	Vishay	VJ1111D270JXRAJ
4	1	CM3	DNP	—	—
5	2	CMP1, CMP2	DNP	—	—
6	1	J1	SMA PCB edge	Linx	CONREVSMA003.031

Table 6: Bill of Materials - Device Board					
Item	**Qty**	**Reference**	**Part Description**	**Manufacturer**	**Part #**
1	1	C84	100nF, 50V	Murata	GRM188R71H104KA93D
2	1	C85	10µF, 50V	Murata	GRM32DF51H106ZA01L
3	1	PCB1	Cat3PRU	Coastal Circuits	Cat3DeviceBoard
4	2	CM1, CM11	300pF	Vishay	VJ1111D301KXLAT
5	4	CM2, CM12, CMP1, CMP2	DNP	Vishay	VJ1111D101JXRAT, VJ1111D560JXRAJ
6	3	CM5, CM7, CMP3	DNP	Vishay	VJ0505D101JXCAJ
7	2	CM6, CM8	56pF	Vishay	VJ0505D560JXPAJ
8	1	CMP4	100pF	Vishay	VJ0505D101JXCAJ
9	4	D80, D81, D82, D83	40V, 1A	Diodes Inc.	PD3S140-7
10	1	D84	LED 0603 Green	Lite-On	LTST-C193KGKT-5A
11	1	D85	2.7V 250mW	NXP	BZX84-C2V7,215
12	1	D86	LED 0603 Red	Lite-On	LTST-C193KRKT-5A
13	1	D87	33V, 250mW	NXP	BZX84-C33,215
14	2	J81, J82	.1" Male Vert.	Würth	61300211121
15	2	LM1, LM11	82nH	Würth	744912182
16	1	R80	300mΩ, 1W	Stackpole	CSRN2512FKR300
17	1	R81	4.7k	Stackpole	RMCF1206FT4K70
18	1	R82	422Ω	Yageo	RMCF0603FT422R
19	4	TP1, TP2, TP3, TP4	SMD probe loop	Keystone	5015
20	1	JPR1	Wire Jumper at CM11	—	—
21	4	—	Nylon standoff 7/8" #6-32	Keystone	1093G
22	8	—	Nylon screws 3/8" #6-32	B&F Fastner	NY PMS 632 0038 PH

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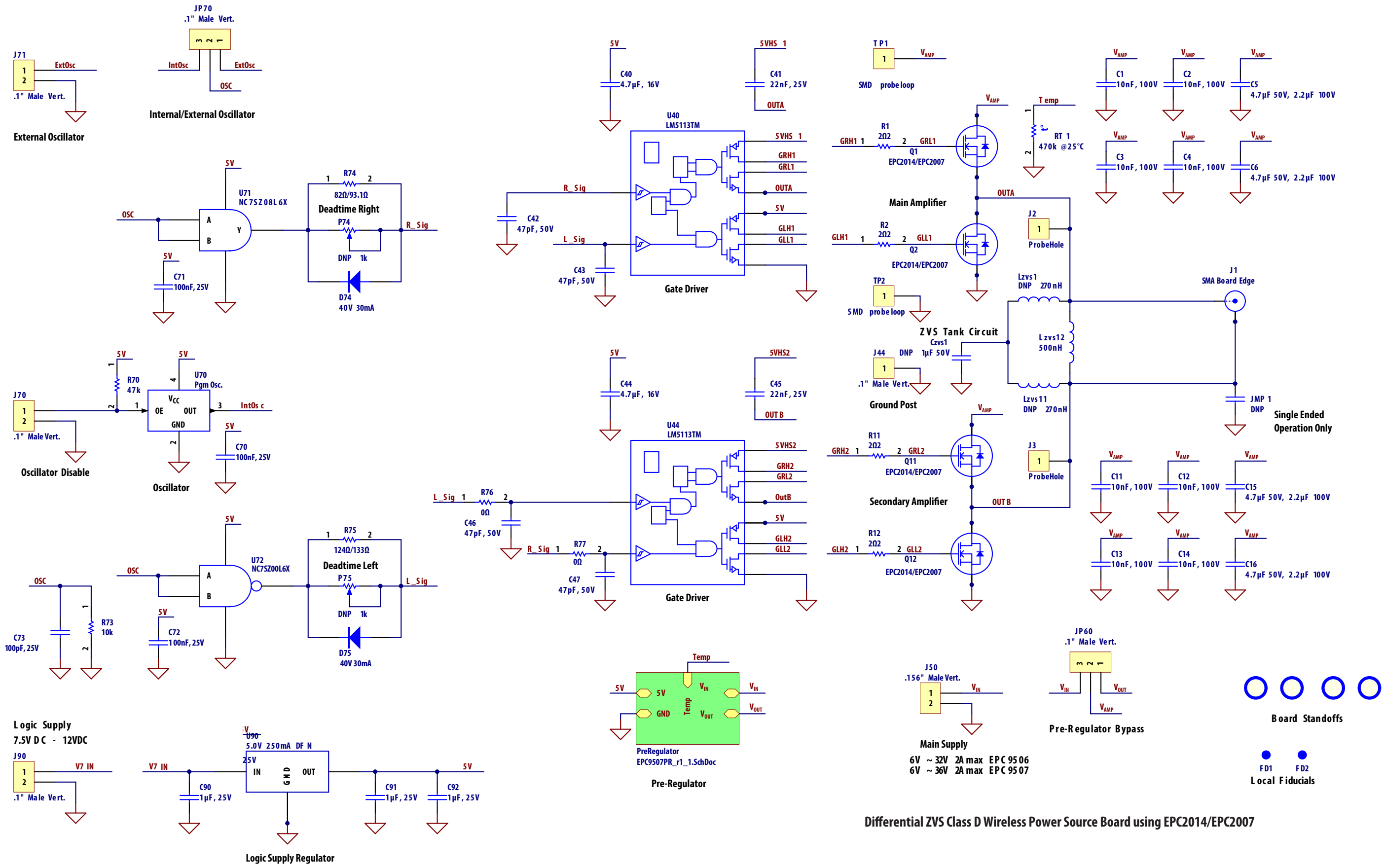

Figure 10: EPC9111/ EPC9112 Source Board Amplifier Schematic

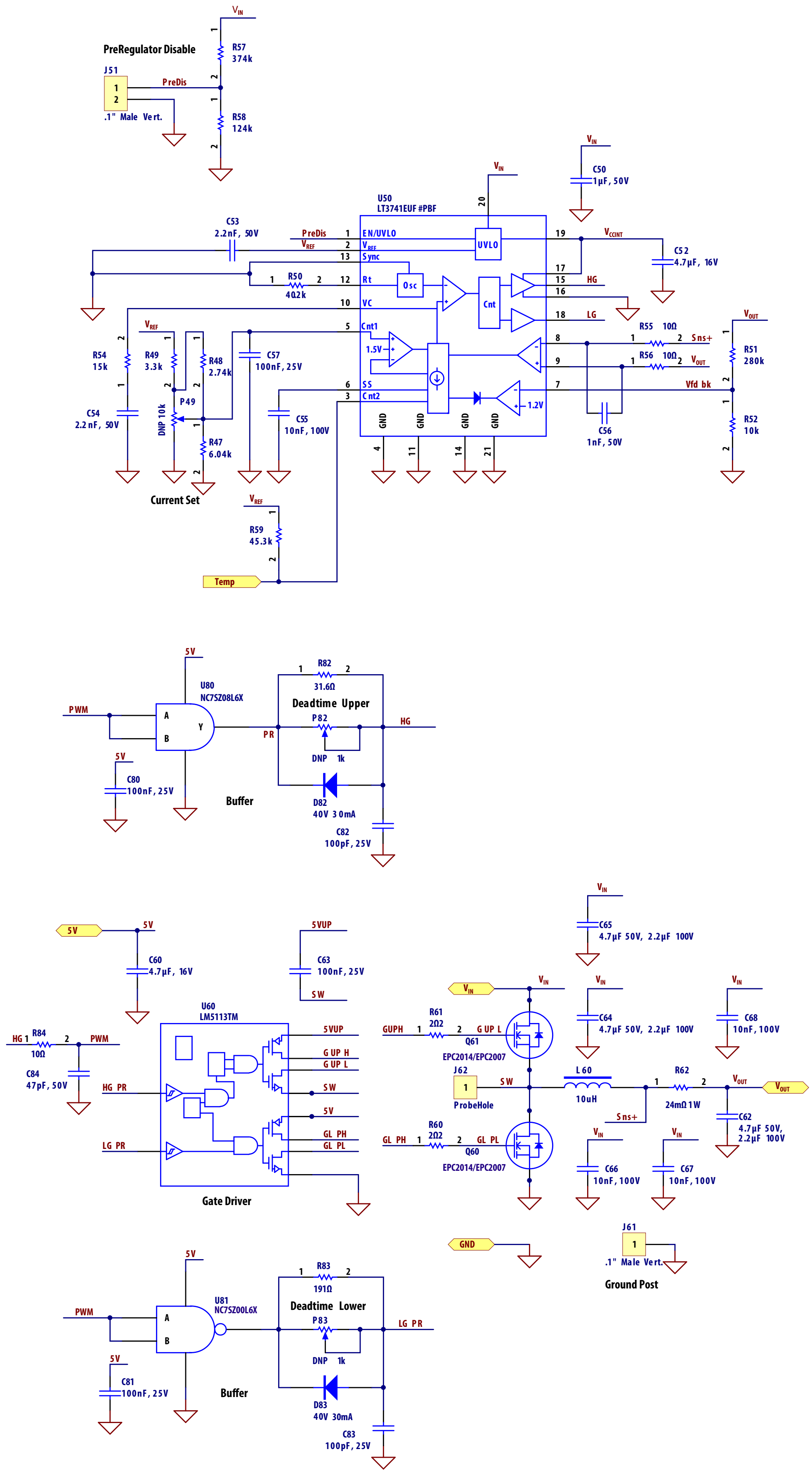

Figure 11: EPC9111/ EPC9112 -Source Board Pre-Regulator Schematic

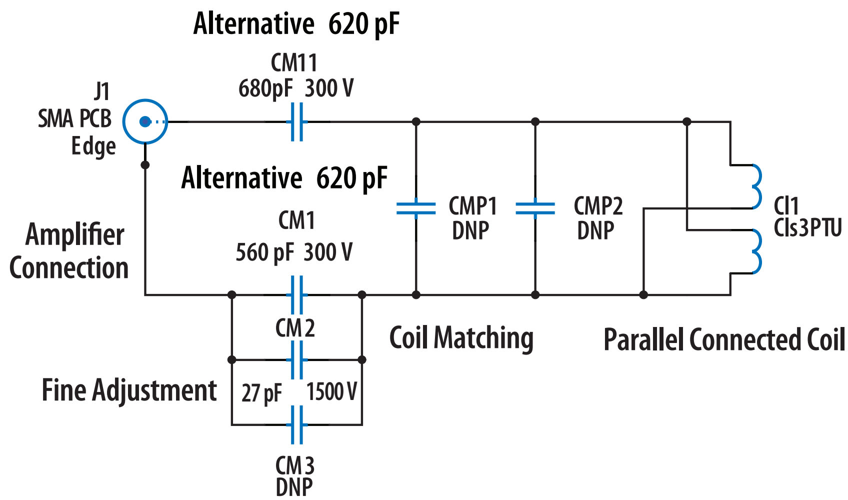

Figure 12: Class 3 Source Board Schematic

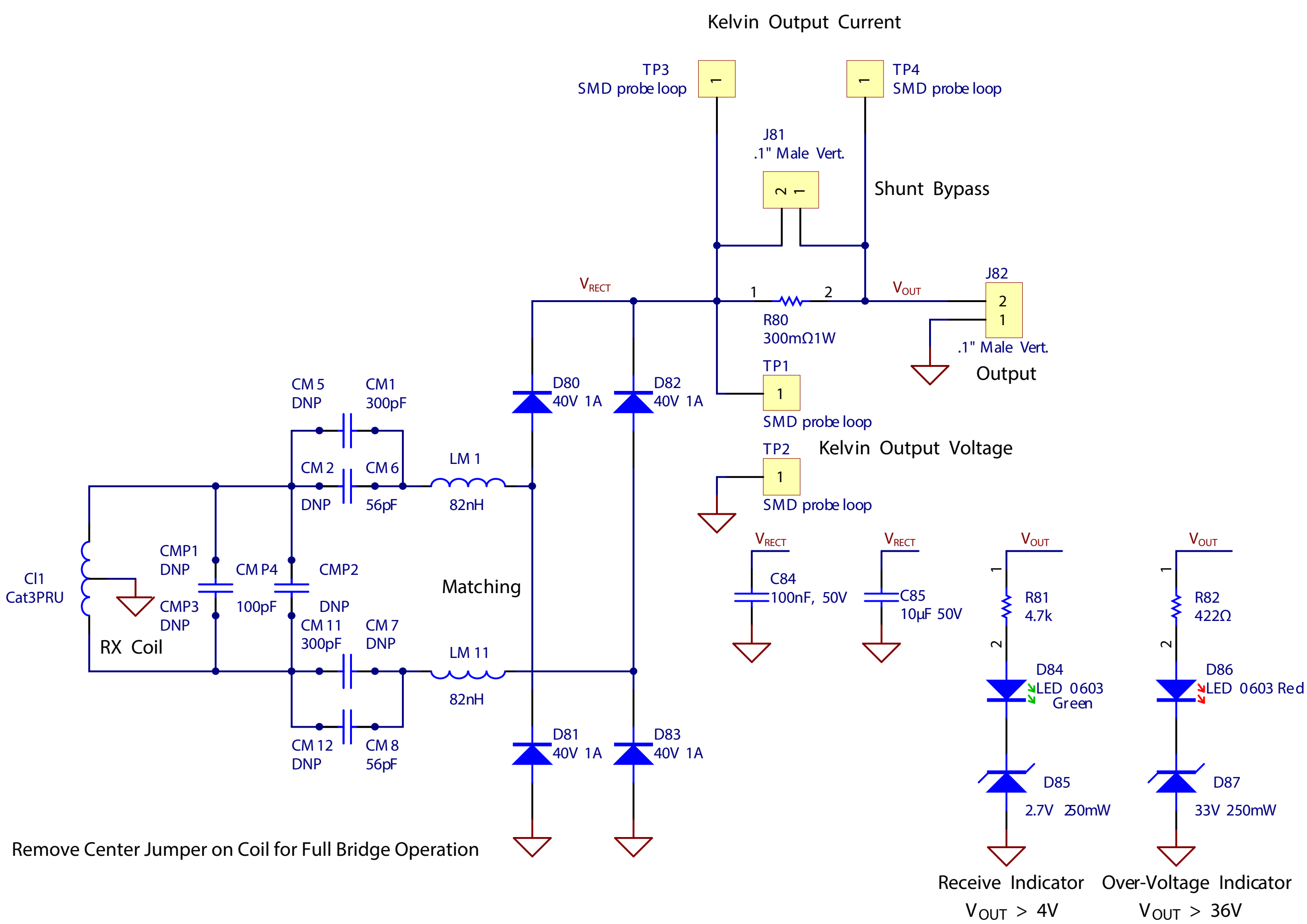

Figure 13: Category 3 Device Board Schematic

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