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Demonstration Board EPC9104 Quick Start Guide

15 W, 6.78 MHz Class D Wireless Power System using the EPC2014 eGaN® FET

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DESCRIPTION

The EPC9104 Wireless power demonstration system is a class D power system capable of delivering up to 15 W into a load operating at 6.78 MHz (Lowest ISM band). 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 converter. The EPC9104 wireless power system comprises four boards namely:

1) A Source Board (Transmitter or Power Amplifier)
2) A Source Coil (Transmit Coil)
3) A Device Coil (Receive Coil)
4) A Device Board (Load or Receiver)

The Source board features the EPC2014 (40 V rated) enhancement mode (eGaN®) field effect transistors (FETs) in a half bridge topology, and includes the gate driver and feedback based phase controller that ensures operation of the system at 6.78 MHz. The source board can also be operated using an external oscillator or direct gate driver signals.

The Source and Device Coils are provided by WiTricity Corporation and have been pre-tuned to operate at 6.78 MHz.

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 various load resistances that can be manually

	Manufacturer	Part #
	Murata	GRM188R71H104KA93D
	Murata	GRM32DF51H106ZA01L
	Diodes Inc.	PD3S140-7
	Linx	CONREVSMA013.062
	Tyco	4-103185-0-02
	Stackpole	CSRN2512FKR300
	TE Connectivity	5-1622820-3
	Rohm Semiconductor	MCR100JZHF4220
	Rohm Semiconductor	MCR100JZHF2740
	Rohm Semiconductor	MCR100JZHF2870
	Rohm Semiconductor	MCR100JZHF1400
	Tektronix	131-5031-00
	Keystone	5015
	WiTricity	190-00038-01

Figure 10: EPC9104-D Device Board Schematic

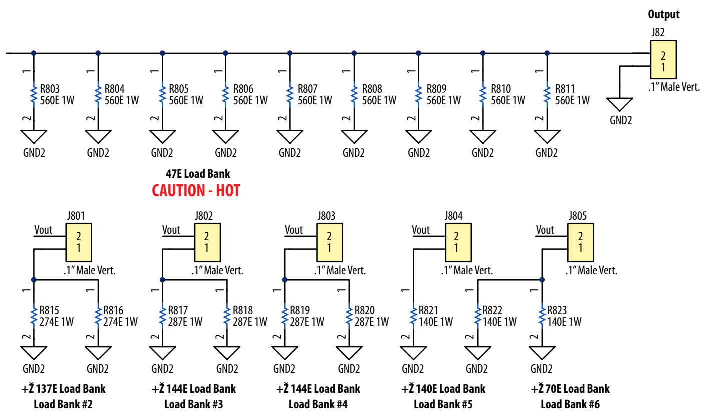
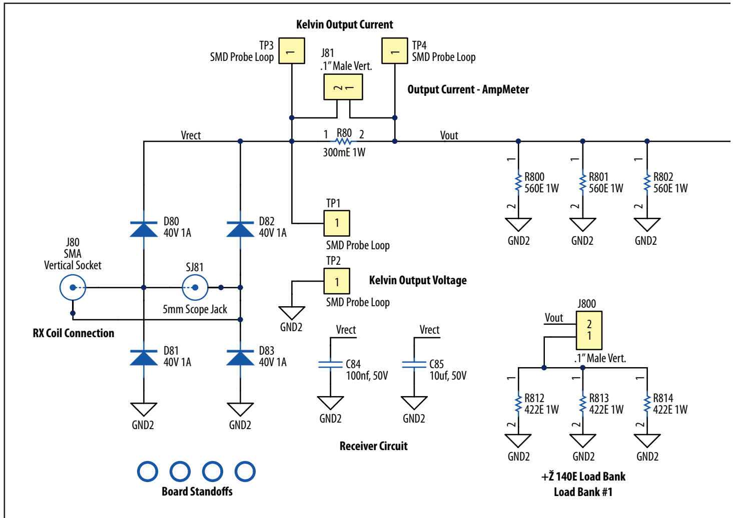


Table 4 : Bill of Materials - Device Board

Item	Qty	Reference	Part Description
1	1	C84	100nF, 50V
2	1	C85	10uF 50V
3	4	D80, D81, D82, D83	Schottky 40V 1A
4	1	J80	SMA vertical Socket
5	8	J81, J82, J800, J801, J802, J803, J804, J805	.1" Male Vert.
6	1	R80	300mE 1W
7	12	R800, R801, R802, R803, R804, R805, R806, R807, R808, R809, R810, R811	560E 1W
8	3	R812, R813, R814	422E 1W
9	2	R815, R816	274E 1W
10	4	R817, R818, R819, R820	287E 1W
11	3	R821, R822, R823	140E 1W
12	1	SJ81	5mm Scope Jack
14	4	TP1, TP2, TP3, TP4	SMD probe loop
15	1	Cl2	Device Coil



programmed to specific values to determine the impact of load resistance on the performance of the system.

Both the source and device boards come equipped with various probe points to facilitate simple waveform measurement and efficiency calculations. A complete block diagram of the system is given in Figure 1.

For more information on the EPC2014 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.

Reverse Engineering of the Source and Device coils is prohibited and protected by copyright law. For additional information contact WiTricity Corp. direct or EPC for contact information.

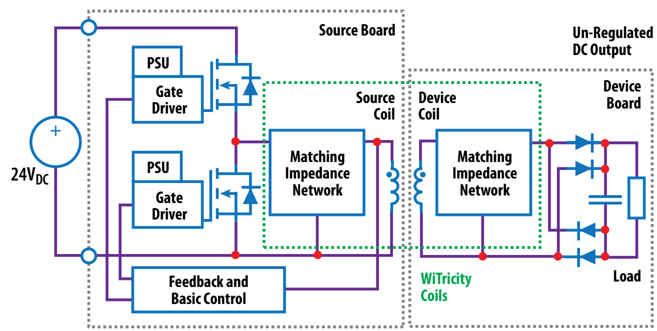


Figure 1: Block Diagram of EPC9104 Demonstration System

ASSEMBLY PROCEDURE

Although the EPC9104 demonstration unit comes mostly pre-assembled, the standoffs need to be attached to the system prior to testing. The standoffs raise the boards 2 inches above the work surface to ensure that metal work surfaces do not interfere with the magnetic fields of the coils. Figure 2 shows the location and allocation of the standoffs for the system. It is recommended to tighten the nuts by hand to prevent over tightening them.

If the Voltage feedback cable needs to be attached, use caution when installing as the Source Coil PCB is thin and can easily break.

When attaching the heat-sink, observe that it lies flat (parallel) with respect to the PCB to ensure proper contact to both FETs and the gate driver IC. Do not over tighten the screws as this can damage the screws, thermal interface material, and/or the FETs.

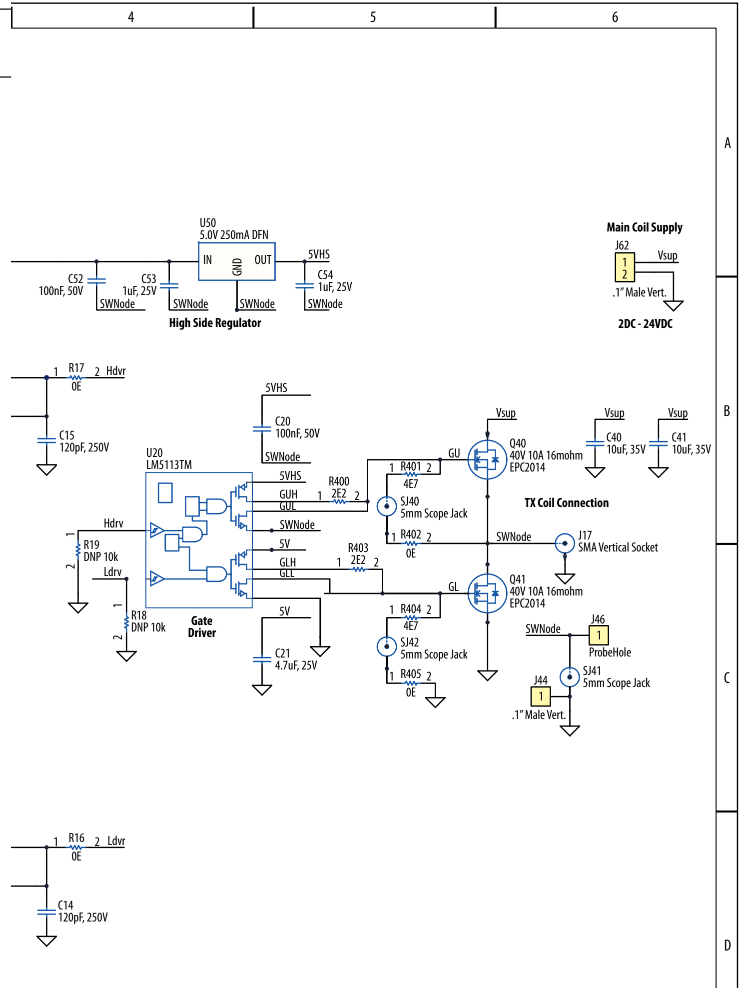
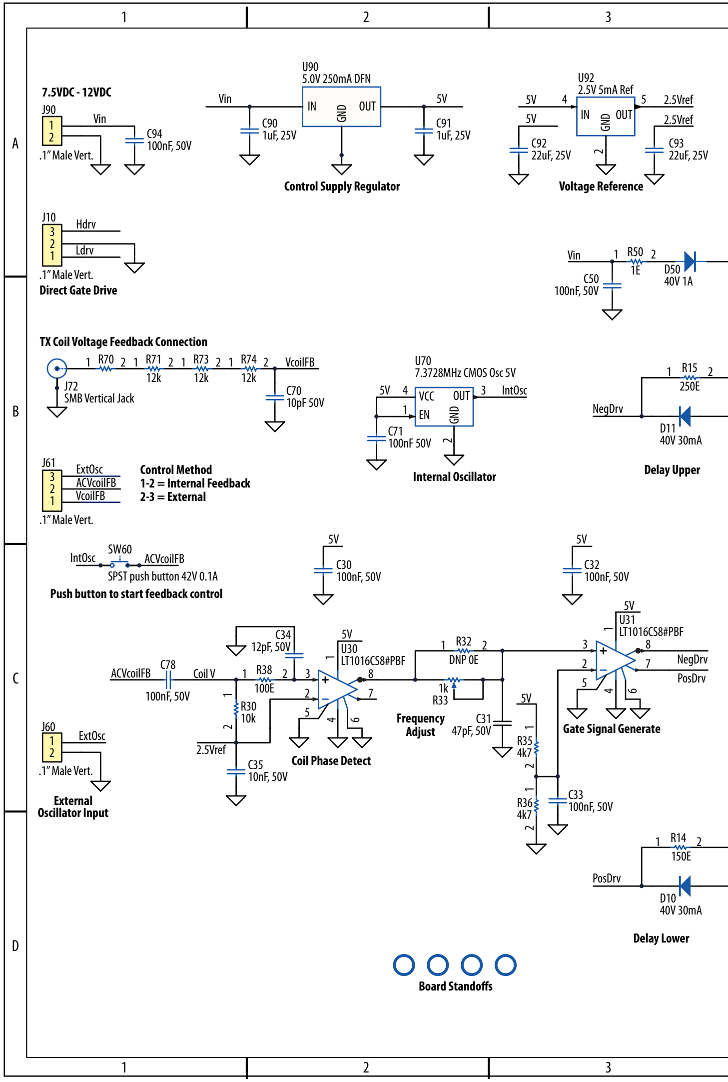


Figure 9: EPC9104-S Source Board Schematic



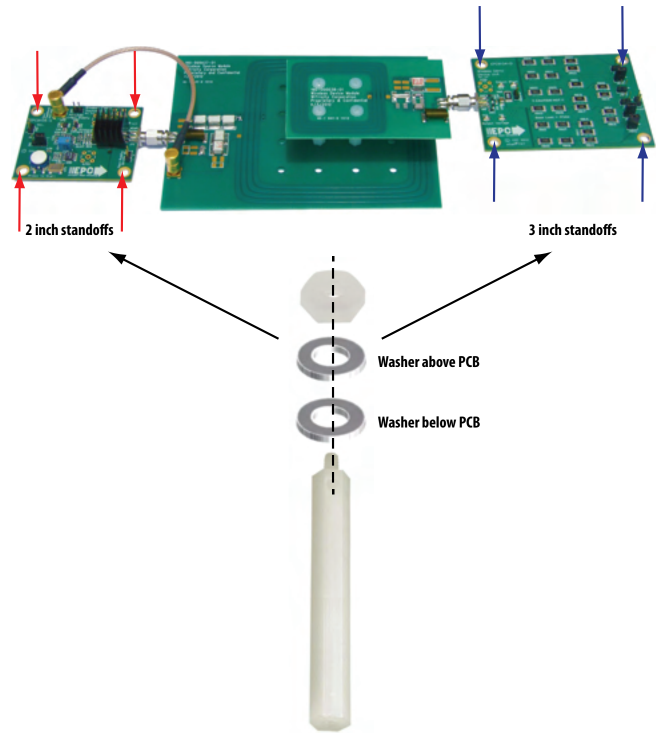


Figure 2: Standoff Assembly for the EPC9104 Wireless System

QUICK START PROCEDURE

The EPC9104 demonstration system is easy to set up and evaluate the performance of the EPC2014 eGaN FET in a wireless power application. Refer to Figure 3 though Figure 6 for proper connection and measurement setup before follow the testing procedures.

The EPC9104 can be operated using any one of three alternative methods:

a. Using the built-in phase follower controller.

b. Using an external oscillator.

c. Using direct gating signals.

a. Operation using the built-in phase follower controller

The phase follower controller uses the coil feedback voltage to generate the gating signals that allow for precise frequency control, regardless of load. The frequency has been pre-set by EPC to 6.78 MHz.

1. Make sure the entire system is fully assembled prior to making electrical connections.
2. With power off, connect the main input power supply bus to $+V_{IN}$ (J62). 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. Set the load to the desired value (see table for setting jumpers or use an appropriate external load).

	Manufacturer	Part #
	TDK	C1608C0G2E121J
	Murata	GRM188R71H104KA93D
	TDK	C1608X5R1C475K
	Murata	GRM1885C1H470JA01D
	Murata	GRM1885C1H120JA01D
	Murata	GRM188R71H103KA93D
	Taiyo Yuden	GMK325AB7106MM-T
	TDK	C1608X7R1E105K
	Murata	GCM1885C1H100JA16D
	Kemet	C0603C223K3RACTU
	Diodes Inc.	SDM03U40-7
	Diodes Inc.	PD3S140-7
	Tyco	4-103185-0-03
	Tyco	4-103185-0-01
	Tyco	4-103185-0-02
	Linx	CONREVSMA013.062
	TE Connectivity	1-1337482-0
	EPC	EPC2014
	Yageo	RC0603FR-07150RL
	Yageo	RC0603JR-07240RL
	Stackpole	RMCF0603ZT0R00
	Yageo	RC0603JR-0710KL
	Murata	PV37Y102C01B00
	Yageo	RC0603JR-074K7L
	Panasonic	ERJ-3GEYJ101V
	Yageo	RC0603FR-071RL
	Yageo	RC0603JR-0712KL
	Yageo	RC0402JR-072R2L
	Panasonic	ERJ-3GEYJ4R7V
	Tektronix	131-5031-00
	C & K Components	1.14100.5030000 & 5.46167.3010209
	Texas Instruments	LM5113TM
	Linear	LT1016CS8#PBF
	Microchip	MCP1703T-5002E/MC
	CTS	CB3-3C-7M3728
	National	LM4125AIM5-2.5
	WiTricity	190-00037-01

Table 3 : Bill of Materials - Source Board

Item	Qty	Reference	Part Description
1	2	C14, C15	120pF 250V
2	9	C20, C30, C32, C33, C50, C52, C71, C78, C94	100nF, 50V
3	1	C21	4.7uF, 25V
4	1	C31	47pF 50V
5	1	C34	12pF, 50V
6	1	C35	10nF, 50V
7	2	C40, C41	10uF 35V
8	4	C53, C54, C90, C91	1uF, 25V
9	1	C70	10pF 50V
10	2	C92, C93	22nF, 25V
11	2	D10, D11	Schottky 40V 30mA
12	1	D50	Schottky 40V 1A
13	2	J10, J61	3pin .1" Male Vert.
14	1	J44	1pin .1" Male Vert.
15	3	J60, J62, J90	2pin .1" Male Vert.
16	1	J71	SMA vertical Socket
17	1	J72	SMB vertical Jack
18	2	Q40, Q41	40V 10A 16mE
19	1	R14	150E
20	1	R15	240E
21	4	R16, R17, R402, R405	0E
22	3	R18, R19, R32	DNP
23	1	R30	10k
24	1	R33	1k
25	2	R35, R36	4k7
26	1	R38	100E
27	1	R50	1E
28	4	R70, R71, R73, R74	12k
29	2	R400, R403	2E2
30	2	R401, R404	4E7
31	3	SJ40, SJ41, SJ42	5mm Scope Jack
33	1	SW60	SPST push button 42V 0.1A
34	1	U20	100V eGaN Driver
35	2	U30, U31	15ns Comparator
36	2	U50, U90	5.0V 250mA DFN
37	1	U70	7.3728MHz CMOS Osc 5V
38	1	U92	2.5V 5mA Ref
39	1	Cl1	Source Coil

5. Make sure the jumper (J61) is in the internal feedback position (default 1-2)
6. Turn on the control supply – make sure the supply is between 7 V and 12 V range (8.5 V is recommended).
7. Turn on the main supply voltage to the required value (do not exceed the absolute maximum voltage of 24 V on V_{OUT}). To ensure that the circuit starts, it is recommended to start at 8 V and increase or decrease to the desired value.
8. If the unit does not self-start in step 7, then press the start button and hold for at least 2 seconds. Observe that the system operates on its own once the button has been released. Pressing the start button will connect the internal oscillator to the feedback circuit to help establish the currents and voltages in the system to function on its own upon release of the start button. The internal oscillator is set to 7.372 MHz (well above the operating point) and it may be necessary to increase the voltage or reduce the load to start the circuit.
9. Once operational, adjust the main supply voltage and load within the operating range and observe the output switching behavior, efficiency and other parameters.
10. 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.

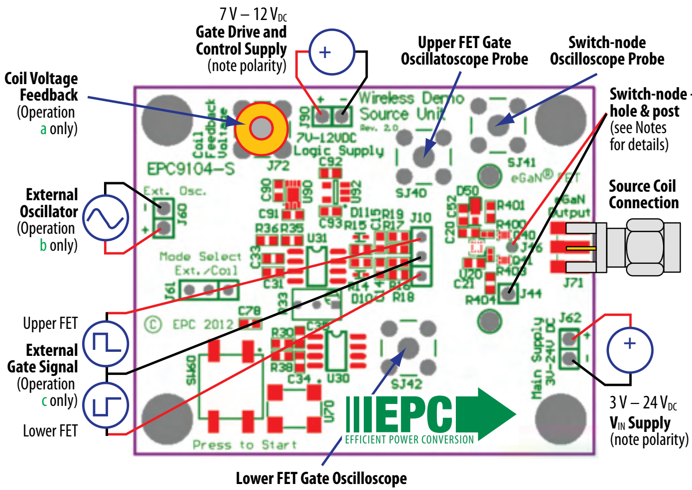


Figure 3: Proper Connection and Measurement Setup for the Source Board

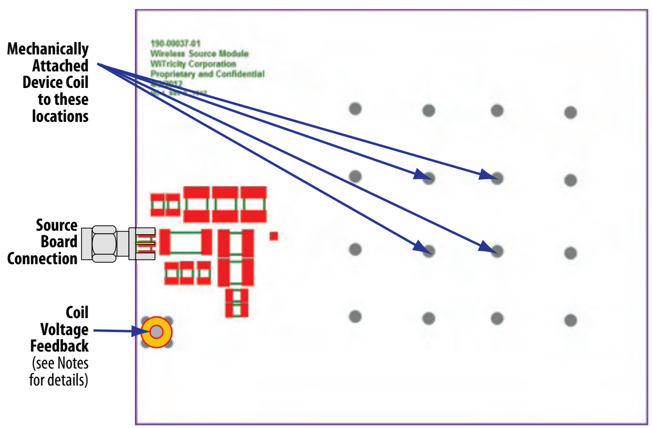


Figure 4: Proper Connection and Measurement Setup for the Source Coil

- Avoid contact with the load bank surface as it can be hot when in operation.
- Never operate the system without a load or a load less than the minimum built into the Device board as this can cause currents in the source circuit to become very high and lead to over-current failure.
- Always make use the ammeter is connected to the load circuit when NOT using the built-in load current shunt. An open circuit can cause currents in the source circuit to become very high and lead to over-current and/ or over-voltage failure.
- Do not change load jumper settings when circuit is in operation.
- Do not press the start button after the system has started and is operating on its own when using the coil voltage feedback method.
- Never press the start button when using an external oscillator for control.
- Never disconnect any of the coils while the circuit is in operation.
- When attempting tests with multiple device loads, always make sure at least one device load is correctly set and physically in proximity to the source coil such that the system operates within specifications.
- When conducting tests near or at full power, always monitor the temperature of the heat-sink and matching circuit inductors to ensure that operation is within specifications.
- Never attempt to monitor, using standard oscilloscope probes, the upper gate voltage (SJ40) simultaneously with the lower gate voltage (SJ42) with any voltage applied to the main circuit (J62). The oscilloscope probes will short out the lower device and induce the possibility of a shoot-through condition for the upper device which can lead to failure. The only exception is if the upper gate voltage is being monitored using an approved differential probe, however even this method of measurement must be limited as induced stray capacitances and inductances can significantly alter the performance of the circuit and resulting oscillations may lead to over-voltages and ultimately failure.
- Always use the supplied hardware to re-assembly the unit and never substitute metal screws, nuts and washers for the nylon versions as they may induce short-circuits into the boards.

THERMAL CONSIDERATIONS

The EPC9104 demonstration system showcases the EPC2014 eGaN FET in a wireless application. Although the electrical performance surpasses that for traditional Si devices, their relatively smaller size does magnify the thermal management requirements. The EPC9104 is intended for bench evaluation with low ambient temperature and convection cooling with load power up to 10 W (the heat-sink MUST be mounted to the board). The addition of forced air cooling can significantly increase the power output of this system, but care must be taken to not exceed the absolute maximum die temperature of 125°C.

NOTE. The EPC9104 demonstration system does not have any current or thermal protection on board. The source coil matching inductor will also dissipate significant power at load power > 10 W and care must be taken to force air cool this inductor too during operation.

GENERAL PRECAUTIONS

- Do not operate the board without a heat-sink as the FETs will overheat and fail.
- Avoid contact with the coil feedback voltage as it can be as high as 300 Vpeak.
- Do not operate the system below resonance as the load will appear capacitive and the losses in the FETs will become very high and lead to thermal failure. When testing the system at various frequencies, always start higher than 6.78 MHz and slowly reduce the frequency, whilst monitoring the source coil current, until the desired setting or the peak amplitude has been reached (resonant point). Operating below this frequency is considered below resonance.
- Do not operate the system on a solid metal (or conductive) surface without the standoffs provided as this will shunt the magnetic field and lead to overcurrent of the FETs.
- Do not apply magnetic materials to the coil magnetic fields as this will shift the resonant operating points and can lead to failure.

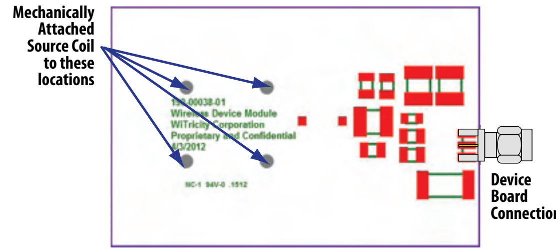


Figure 5: Proper Connection and Measurement Setup for the Device Coil

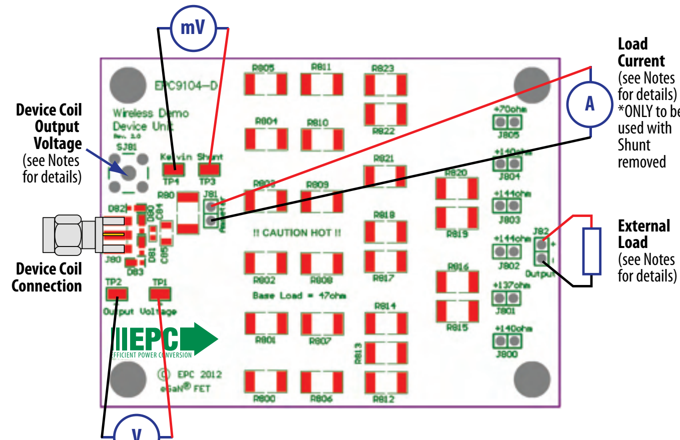
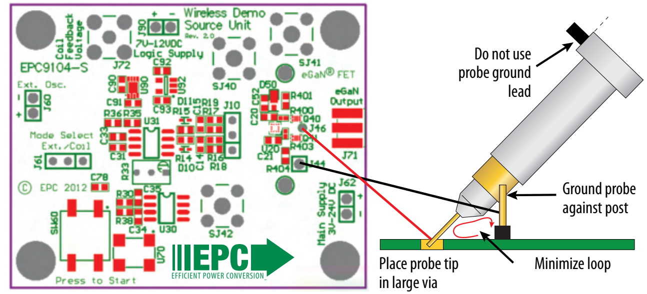


Figure 6: Proper Connection and Measurement Setup for the Device Board

b. Operation using an external oscillator

Using an external oscillator allows the user to specify an operating frequency. The external oscillator voltage may be pure AC (sine or square wave) or have a DC offset (see Table 1 for voltage limits).

1. Prior to commencing with testing, jumper (J61) will need to be moved from its 1-2 position (default) to position 2-3.
2. Using this method, it is not necessary to connect the source coil feedback voltage RF cable between the source coil and the source board
3. Make sure the entire system is fully assembled prior to making electrical connections.
4. With power off, connect the main input power supply bus to $+V_{IN}$ (J62). Note the polarity of the supply connector.
5. With power off, connect the control input power supply bus to $+V_{DD}$ (J90). Note the polarity of the supply connector.
6. Set the load to the desired value (see table for setting jumpers or use an appropriate external load).
7. Turn on the control supply – make sure the supply is between 7 V and 12 V range (8.5 V is recommended).
8. Turn on the main supply voltage starting at 0 V and increase slowly to the required value (do not exceed the absolute maximum voltage of 24 V on V_{OUT}). Observe that the system operates.



* Can only be used if heat-sink has been removed and post has been installed

Figure 7: Proper Measurement of Switch Node using the hole and post

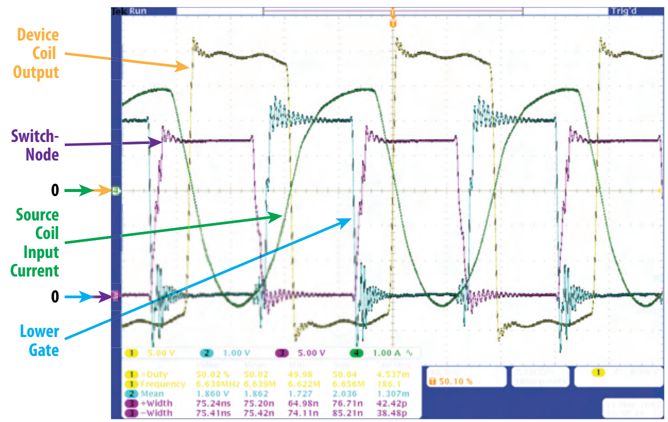


Figure 8: Typical Waveforms for V_{IN} = 24 V (6.639 MHz) into 23 Ω load
CH1: (V_{OUT}) Device Coil Output Voltage – CH2: (V_{GS-L}) Lower FET Gate Voltage
CH3: (V_{OUT}) Switch node voltage – CH4: (I_{OUT}) Source Coil Current

LOAD SETTINGS

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The device board comes pre-equipped with various loads that can be manually programmed to specific values. Table 2 provides a list of all possible combinations to set the load. This list is the recommended list and it can be recognized that there are a total of 64 combinations, of which many load values will repeat.

Table 2 : Device Board Load Resistance Jumper Settings

Setting	J800	J801	J802	J803	J804	J805	Load Resistance [Ω]
1	out	out	out	out	out	out	47.0
2	out	out	in	out	out	out	35.5
3	in	out	out	out	out	out	35.3
4	out	in	out	out	out	out	35.1
5	out	out	in	in	out	out	28.6
6	in	out	in	out	out	out	28.5
7	out	out	in	out	in	out	28.4
8	in	out	out	out	in	out	28.3
9	in	in	out	out	out	out	28.2
10	in	out	in	in	out	out	23.8
11	in	in	out	in	out	out	23.7
12	in	in	out	out	in	out	23.6
13	out	in	out	out	out	in	23.5
14	in	out	in	in	in	out	20.5
15	in	in	in	in	out	out	20.4
16	in	in	in	out	in	out	20.3
17	out	in	out	out	in	in	20.2
18	in	in	in	in	in	out	17.9
19	in	in	out	out	in	in	17.8
20	in	in	out	in	in	in	15.9
21	in	in	in	in	in	in	14.3

9. Once operational, adjust the main supply voltage and oscillator frequency within the operating range and observe the output switching behavior, efficiency and other parameters.
10. For shutdown, please follow steps in the reverse order. Start by reducing the main supply voltage to 0 V followed by steps 7 through 4.

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

Symbol	Paramter	Conditions	Min	Max	Units
V_{DD}	Control Supply Input Range		7	12	V
V_{IN}	Bus Input Voltage Range		3	24	V
V_{OUT}	Switch Node Output Voltage			40	V
I_{OUT}	Switch Node Output Current			10*	A
V_{extosc} #	External Oscillator input threshold	Input 'High'	0	5	V
		Input 'Low'	-5	0	V
V_{HIN}, V_{LIN}	Gating Signal Voltage Range		-0.3	15	V
V_{fdbk}	Coil feedback voltage input			300pk	V

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

Accepts AC signals with peak magnitude up to 10 V and with DC offset up to 5 V_{DC}.

c. Operation using direct gating signal control

This method of operating the wireless system is similar to operation using an external oscillator except the user now directly controls the gating signals. It is important to note that the user MUST provide the necessary dead-time between the high side (29 ns recommended) and low side (18 ns recommended) signals and also ensure that both gating signals cannot be high at the same time as these features have not been built into the circuit when sourcing the gating signals directly. This has been an intentional omission allowing users to integrate their custom circuits to as close to their needs as possible. With this method the entire phase follower feedback circuit is bypassed.

1. Prior to connecting the source board to the source coil, resistors R16 (0 Ω, size 0603) and R17 (0 Ω, size 0603) must be removed from the board. Resistors R18 (10 kΩ, size 0603) and R19 (10 kΩ, size 0603) must be inserted.
2. Using this method, it is not necessary to connect the source coil feedback voltage RF cable between the source coil and the source board.
3. Make sure the entire system is fully assembled prior to making electrical connections.
4. With power off, connect the main input power supply bus to $+V_{IN}$ (J62). Note the polarity of the supply connector.
5. With power off, connect the gate drive input signals to (J10, Pin-1 = Low-side, Pin-2=Ground, Pin-3=High-side) and activate signals. Make sure the gating signal are within specifications.
6. With power off, connect the control input power supply bus to $+V_{DD}$ (J90). Note the polarity of the supply connector.
7. Set the load to the desired value (see table for setting jumpers or use an appropriate external load).
8. Turn on the control supply – make sure the supply is between 7 V and 12 V range (8.5 V is recommended).
9. Turn on the main supply voltage starting at 0 V and increase slowly to the required value (do not exceed the absolute maximum voltage of 24 V on V_{OUT}). Observe that the system operates.
10. Once operational, adjust the main supply voltage and oscillator frequency within the operating range and observe the output switching behavior, efficiency and other parameters.
11. For shutdown, please follow steps in the reverse order. Start by reducing the main supply voltage to 0 V followed by steps 8 through 4.

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 (SJ41) and the Device Coil Voltage (SJ81) that is compatible with 5 mm Tektronix probes.

Alternatively, by removing the heat-sink, the Source Coil Voltage can be measured by placing the oscilloscope probe tip through the large via on the switch-node (J46 - designed for this purpose) and grounding the probe directly across the GND post (J44 - must be installed). See Figure 7 for proper scope probe technique. Using this technique will significantly limit the operating power as the FETs and gate driver IC will heat up significantly and care must be taken not to exceed the junction temperature of the eGaN FETs.